Behavioural Response Study with Australian humpback whales and seismic air guns

by

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Preface

This proposal has had a long gestation during which, in our opinion, it has improved substantially by incorporating feedback, advice, ideas and perspectives from many expert stake holders and scientific reviewers. It has developed a long way from its original concept through the continued interaction between the investigators and JIP representatives.

This is a revision of a proposal ―Controlled exposure experiments with Australian humpback whales and seismic air guns.‖ submitted on 30 July 2009 to the E&P Sound and Marine Life Joint Industry Program. It followed a pre-proposal entitled ―Controlled exposure experiments to examine the effects of seismic air gun arrays on humpback whales,‖ which was submitted on 30 Nov 2008 and was funded to develop the experimental design. This in turn arose from a proposal submitted in response to JIP-RFP 08-03, Release Date: 1 February, 2008: ―Controlled Exposure Experiments involving Whales and Air guns.‖ Over this period, there have been a number of planning meetings involving JIP representatives and the investigators, and meetings in November 2009, with the Minerals Management Service (MMS), JIP and other stakeholders and three of the Principal Investigators.

The revision of this proposal takes account of the many reviews, comments, ideas and suggestions provided on the 2009 proposal. We are very grateful to the many who contributed. In particular, the substantial efforts and continued support of Roger Gentry, Rodger Melton and John Young are much appreciated. Five anonymous scientific reviewers, expert advice from William Ellison and Brandon Southall, MMS and JIP representatives and a review by Robert Gisiner, are much appreciated. John Hughes has also provided useful advice.

There were a number of suggested additions to the project and a few suggestions where we could cut back. Overall, there were more suggested additions than deletions, and to incorporate all would have significantly increased the cost of the project. In general, there is a trade-off between trialling as many different types as exposure with the need to obtain an adequate sample size for each exposure. Every new type of exposure or treatment requires an adequate number of samples and controls, as many as each of those already planned. We have therefore tried to find the best compromise that allowed us to include these additional components without losing too much. This has led to a redesign of some aspects. An example is the advice of the importance of adding a second tow path for the experiments. The value of this is that it would vary the tow path relative to the direction of migration and the topography (whale paths cover a wide range of directions so variation in the direction of tow paths relative to whale paths would occur even with one tow path). To do all the tests on two tow paths instead of one would double the time at sea and substantially increase the cost, since time at sea is a major component of the total cost. On the other hand there were also suggestions that we planned to use too many different combinations of air guns in the experiments and that we could reduce these. By reducing the number of air gun combinations and some redesign, we have been able to accommodate the two tow paths for the experiments other than that with the full seismic array. Not all tests or treatments will be used on the second tow path and one originally planned will be removed altogether. On balance, this gives a better design that originally proposed. It is not possible to reduce the sampling for the full array, and running this on two tow paths has significantly increased the field effort and expense off the west coast. We have been able to maintain the budget overall by savings on the purchase and operation of the small air gun arrays, since this is not now to be used to emulate a full array.

There remain some uncertainties in the design of the experiment where advice from the stakeholders is required. Most of these do not have to be resolved for the first series of experiments which are planned for 2010, so need not delay the project. These include the actual air gun capacities and configuration to be used in the study of the first few stages of ramp-up and the design of the full scale commercial array for the experiment in 2013.

We have provided some options for cutting costs by giving options to remove components of the project, with a discussion of the consequent loss in value to the project outcome compared with the cost saving.

We had been working with the Australian Federal Government agency Geosciences Australia in developing the component of the proposal that deals with study of the effects of the first few components of ramp-up (all except the full array). The idea was that their staff with years of experience in maintaining and operating air gun arrays would take charge of the air gun operation and provide a significant amount of the equipment required. We have just heard that they are no longer able to participate. As a consequence, we need to find alternative experts in operation of air guns to participate in the experiments. We are currently investigating companies in Australia that do this kind of work and plan to report before the JIP meeting in March 2010, with potential suppliers and cost. In the meantime, we have reverted to the estimates provided in 2009 as a temporary measure. This is based on estimates for purchase of the air guns, compressor and ancillary equipment, and staff to build, maintain and operated the air guns through Curtin University.

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A. Introduction

A.1 Abstract

This project aims to provide information that will reduce the uncertainty in evaluating impacts of seismic surveys on humpback whales. It will also assess the effectiveness of ramp-up as a mitigation measure, and the potential to improve design of ramp-up. The results will be in a form useful for designing management of seismic surveys and mitigation procedures.

To achieve this we will conduct experiments in which humpback whales migrating along Australian coasts are exposed a full commercial air gun array and to components of ramp-up, while we observe the reactions of the whales and measure a wide range of variables likely to affect the reactions. The whales are moving away from the breeding grounds and show behaviour that is a combination of breeding, social interaction, and surface active behaviour, as well as migration – all except feeding behaviour. Their behaviour is similar to that reported from other parts of the world. The seasonal presence of whales in the study areas is very predictable, having shown little variability for many years. The migration provides a daily turnover of whales ensures that no individual will be exposed twice.

Measured whale reactions will include changes in physical behaviour and vocalizations. Received sound levels (intensity and energy density or sound exposure) of the air guns at the whales will be determined from measurements at many positions in the study areas, using measured and modelled propagation loss. Digital recording tags such as DTAGs (Johnston and Tyack, 2003) will also be attached to whales for this purpose and for recording the dive profile. Longer term tags will be used to obtain the dive profile over periods of several days. Measurements will also include ambient noise and received levels of other stimuli such as vocalizing whales and vessels. Whales will be tracked visually and vocalizing whales acoustically while in the study areas.

The experiments are designed to provide results that would be generally applicable to humpback whales with similar behaviour worldwide. This will be achieved by measuring a sufficient range in the values of the variables affecting the responses to allow the general dependence on these variables to be determined, thus separating the results from the specific conditions of measurement. To do this we will study two different humpback whale populations in different environments (with differing water depths and sound propagation) and use a range of air gun array sizes to vary the received level as a function of distance. Variation in other variables such as whale behaviour, ambient noise and weather occurs naturally. By determining the values of these variables for any new site, the response can then be predicted.

This approach goes beyond a simple dose response concept where the response is related only to the received noise level. The response is considered to be a multivariate function and the experiments and analysis are designed to tease out the relative importance and contribution of the variables affecting the response. In other words the intention is to place the response into the context of the whale behaviour, the environmental conditions and relative interactions between whales and seismic array. We believe that, apart from this being good science, this approach will also enable the most complete understanding of the how these whales interact with seismic exploration noise which, in turn, will enable the development of reasonable mitigation strategies.

There will be two experimental regimes and two study sites: one offshore and one inshore. One experimental regime, used only at the offshore site, will be the exposure of whales to a commercial seismic air gun array. The second regime will involve controlled exposure of whales to components of ramp-up, and will be used at both sites to compare responses to the same stimuli between sites. The inshore site allows more detailed and higher resolution observations by using land based observations and thus provides a larger amount of whale response information and a higher degree of experimental control than possible at the offshore site. Using these detailed observations, we can tease out detailed reactions to individual air gun firings of ramp-up. It will also allow us to obtain the data needed to understand the function of behaviour and vocalizations to relate whale reactions to life functions. It would not be possible, however, to use a full survey air gun array at the inshore site because of the difficulties of working so close to shore, including the difficulties of obtaining permits and ensure that reactions do not drive whales too close to the beach. Control observations will be made at both sites with the vessel towing the air gun array but without firing and also in the absence of the vessel. Varying the seismic exposure and working on two different whale populations helps avoid pseudo-replication (Hulbert 1984; McGregor et al, 1992; McGregor, 2000) and allows generalization, and so a greater predictive capability, of results.

The offshore work will be carried out off Western Australia and the inshore work off east Australia because that is where we get the best combination of the two experimental regimes. Commercial seismic surveys are conducted off Western Australia and somewhat offshore. Geographical conditions and the location of migration paths preclude shore based observations, such as theodolite tracking. At the east coast site, whale migration paths are closer to shore and most whales pass within 10 km of the beach, allowing land-based tracking and observations over a 10 km scale. More than 2000 whales have been tracked visually and more than 400 acoustically in previous experiments at this site. There are no commercial seismic surveys off near the east coast site and it would be difficult to conduct one so close to shore.

The east and west Australian humpback whales form two largely separate populations with only a small amount of interchange (Chittleborough, 1965). Both populations have been studied for many years providing substantial information about their migration, biology, population dynamics (about 38 journal papers and 22 reports) and behaviour and acoustics (18 journal papers and 13 reports). This information is crucial to model and infer the effects of exposure to air guns on life functions. This work has shown that humpback whales show a wide range of behaviours typical of the breeding grounds, with a range of social interactions and communication including song, social vocalizations and surface active behaviour. There is complex interaction between individuals over scales of kilometres. Whale paths through the study areas show considerable meandering from the general southward migration, so the paths cover a wide range of bearings. This would provide a wide range of orientations in movement direction relative to any tow path of an air gun array. Reactions to air guns will be compared with this range of behaviours and other datasets, and reactions to other stimuli such as vocalizing and surface-active whales, high levels of ambient noise, passing vessels and playback of tones and humpback whale vocalizations.

The experimental design of this study (a "before, during, after" or "BDA" design incorporating various treatment effects) will follow closely and build on that of many previous seismic and non-seismic studies (i.e. Tyack 1983; Mobley et al, 1988; Madsen et al, 2002; McCauley et al, 2003; Miller et al, 2000; Miller et al, 2009). The function of behaviour and vocalizations will be used to model and infer effects on life functions, in order to relate dose response to biologically significant effects. Results of previous studies have been used in power analysis to determine sample sizes needed for experiments. Statistical analysis will include Generalized Linear Mixed Models (GLMM) using multiple measures of behavioural response and spatial interaction.

GLMMs will be developed incorporating the range of variables allowing us to test the effects of the different variables on the response. It also allows the incorporation of variance associated with using more than one observation per experimental unit, as in the case of sequential behaviour of an individual whale.

The project team includes experts in the wide range of scientific disciplines required to execute the project. Team members have substantial experience in humpback whale behaviour and vocalizations at the two sites, as well as measuring reactions to noise, the use of air guns, and playback of tones and vocalizations. The team includes experts in whale behaviour, whale vocal behaviour, underwater acoustics, statistics, whale tagging, air gun operation and experimental design.

A.2 Statement of objectives or questions to be addressed

The broad objectives are:

a) To determine the response of humpback whales to a typical commercial seismic survey in terms of the variables affecting the response, such as the received sound level, relative movements of seismic array and whales and distance between them, behavioural state and social category of the whales, and environmental variables.
b) To determine the response of humpback whales to soft start or ramp-up and its components, to assess the effectiveness of ramp-up as a mitigation measure in seismic surveys and the potential for improving the effectiveness.
c) To relate these responses to the range of normal behaviour and the response of the whales to other stimuli, such as passing ships, using the substantial body of knowledge that exists from previous research for the populations studied. Knowledge of the function of the behaviour, the population dynamics and the biology of the whales will allow us to infer and model effects on life functions.

A.3 Hypotheses to be tested

The hypotheses listed below will be tested, recognizing that the results may vary with: received air gun signal level and character; seismic array configuration; relative motion and range of the seismic array and whale; background noise level; social context of the whale or group of whales (e.g. single adult, mother and calf); and the behaviour of the whale at the time of exposure (i.e. migrating, resting or socializing). The aim is to develop response relationships and response thresholds, in terms of the variables listed. Measures of behavioural change or reaction include: changes in course travelled by groups of whales through the study area; the consistency in course travelled (i.e. the changes in course); group speed; dive profile (including deep dive profiles, shallow dive profiles and surface intervals); surface-active behaviour; sightability; and spatial relationships between individuals or other groups, especially mothers and calves. Measures of changes in vocalization include song structure, social sound type and characteristics and vocalization amplitude (source level).

Hypotheses:

1. Humpback whales show changes in behaviour, including vocal behaviour, when exposed to a commercial seismic air gun array.

2. The threshold of observed changes in behaviour depend on

a) received noise level

b) distance of the whale from the array independently of received level
c) whale social category (male, female, calf) and social context
d) direction of air gun movement relative to the whale
e) ambient noise level

3. The behavioural changes lie within the range of those observed in the absence of human activity.

4. Humpback whales show changes in behaviour, including vocal behaviour, when exposed to components/stages of ramp-up:
a) a single air gun,
b) four air guns
c) ramp-up from one to four air guns
d) full ramp-up of a commercial air gun array

5. Humpback whales move away from the air guns when exposed to component/stages of ramp-up.

A.4 Summary of Methods and Approach

We will conduct experiments in which humpback whales migrating along Australian coasts are exposed a full commercial air gun array and to some components of ramp-up, while we observe the reactions of the whales and measure a wide range of variables likely to affect the reactions. Exposure to components of ramp-up will be done at a near shore site on the east coast where a high resolution observations are possible with shore based observations. Exposure to a full seismic array will be done at an offshore site off the west coast. Aspects of the east coast experiments will be repeated off the west coast to compare the reactions of the two populations. Observations will include vessel based observations of whale physical behaviour, focal follows (following and observing a focal group), vocalizations, measurements of sound field throughout the site, tags such as DTAGs (for received sound field at, and the fine-scale 3D underwater movements of, the tagged whales), longer term tags (for broader scale movements), and biopsies (to determine gender for social context). The inshore site provides additional types of observations and higher resolution observations than are possible offshore, including theodolite tracking of most whales within a 10 km radius, theodolite focal follows of focal groups, and more accurate acoustic tracking of vocalizing whales. This provides greater detail, resolution and sample size than possible offshore, and allows reactions of multiple whales to be determined at several scales. The fine scale work will allow us to tease out the behavioural reactions in terms of the variables likely to affect the reactions such as received level, proximity of source, pattern of movement, social context of the whales). It will provide the context for interpretation of the commercial array trials. It will also provide the information needed to interpret reactions to ramp-up.

All experiments will include controls in which the air gun vessel is towing the air guns but they are not firing, and controls in which the vessel is absent. All focal group observations follow a "before, during, after" design and so each group also acts as its own control. The sound field across the sites during experiments will be determined by multiple spaced measurements of received levels, propagation loss measurements and modelling. The observed behavioural changes at the sites will be compared with the extensive knowledge of normal behaviour and its function, and reactions to other stimuli available from previous studies at these sites. These comparisons will be used to infer effects of air gun exposure on life functions. Varying the seismic array size and configuration will help avoid pseudo-replication to allow generalization of the results.

The results will be analysed by developing generalized linear mixed models in which the contributions of the variables measured to the whale reactions can be determined.

A.5 Statement of the scientific significance of the project

This project will build on previous studies of the effects seismic activity on whales and extend them in a number of areas. The logistic difficulties of studying whales limit the amount of observations that can be made and thus the sample size that can be obtained in experiments for reasonable cost. Studying the effects of noise on behaviour is further complicated by the need to separate observed behaviours associated with the noise stimulus from the range of behaviours that the whales exhibit normally. The experimental procedures to deal with these difficulties have developed in previous experiments over the last 25 years, and the results of these experiments have led to clearer understanding of the important issues that need to be addressed (see B.2 for details). Some experiments produced results that were somewhat uncertain because samples were too limited or the experimental design lacked some important feature such as adequate controls, but these results also showed us how to improve the experimental technique and obtain the sample size required. This project is the next step building on the ones that have gone before.

It will add to the previous work by combining the following:

- The proposed project will combine Behavioural Response Studies (BRS) (also known as Controlled Exposure Experiments) using a commercial seismic array and BRS using individual stages of the ramp-up procedure used in seismic surveys (single air gun, four air guns etc.) to determine whale reactions to a wide range of exposures. It will assess whether ramp-up is effective as a mitigation measure.

- Multiple scales of observation will provide significantly greater resolution and detail of behavioural data than most previous experiments.

- It will go beyond a simple dose response study where the dose related only to the received noise and test the contribution of a wide range of variables likely to affect reactions to air gun arrays. It will provide the range in the values of these variables needed to do this and to avoid pseudoreplication, the failure of the experimental design to provide sufficient variety in the samples taken to obtain a representative of the type of stimulus, the subject or other variables that affect the result.

- Variables will be measured over a range of values and multivariate statistical methods such as generalized linear mixed model will be used to tease out the contributions of the different variables, thus making the results generally applicable to humpback whales exhibiting similar behaviour elsewhere. Statistical power analysis has been used to ensure that the planned sample size is adequate to obtain statistically significant results and this analysis will be repeated for each subsequent experiment using data from the previous one.

- The reactions will be placed in the context of normal behaviour and reactions to other stimuli that may be encountered by the whales using the unusually large amount of data on normal behaviour and biology that exists for the populations studied. This will allow us to make progress in making inferences and developing models relating observations to effects to life functions.

B. Body of the Proposal

B.1 The project concept or idea

This project aims to understand how humpback whales react to commercial seismic survey and to ramp-up of the air guns, in a way that can be applied generally to humpback whales exhibiting similar behaviour worldwide. To gain this understanding we need to do more than observe reactions to a seismic survey with ramp-up. We need to measure all the variables likely to affect the reactions of the whales and to determine the dependence of the reaction on each of these variables, so that the results can be used to predict the reactions for any combination of the values of these variables. This requires the measurements to be taken over a range of values for each of these variables during the experiments.

The populations of whales to be studied are migrating away from the breeding grounds and show behaviour that is a combination of breeding, social interaction, and surface active behaviour, as well as migration – all except feeding behaviour. Their behaviour is similar to that reported from other parts of the world.

While it is often implicitly assumed that reactions of whales to human activity is dominated by the noise they hear, the lack of consistency over many experiments in estimating the threshold received noise level to cause a reaction shows that the reality is far more complicated. Richardson et al. (1995) cite many such experiments and the threshold noise level for baleen whales to react varies over a range of 50 dB, the lowest being at levels that would were only audible because of the low levels of ambient noise at the time. Such a wide variation is of little use in management unless the other factors affecting the reactions are incorporated into the management process. Studies of baleen whale reactions to air guns also show significant variability. Richardson et al. (1995) summarize the results of a number of studies that gray and bowhead whales generally avoided seismic vessels when the received levels were in the range 150 – 180 dB re 1 μPa. For example, feeding humpback whales showed no avoidance at a received level of 172 dB re 1 μPa (Malme et al., 1985), while migrating humpback whales showed avoidance at levels 157 – 164 dB re 1 μPa, while for females with calves resting in a large bay during the migration, the mean level for avoidance was 140 dB re 1 μPa (McCauley et al. 2003). Differences in behaviour may be a significant factor here.

A number of studies relate the avoidance observed to received level and the distance from the source. Since noise level generally decreases with distance from a source, these two variables are correlated in any particular set of conditions, so that it is difficult to separate the effects of received level and distance, or determine which the more significant effect is. Sound propagation varies widely with location and time varying properties of the water column. The relationship between received sound level and distance therefore varies widely between different locations and conditions, making it difficult to apply results obtained in one set of conditions. We therefore need an experimental design that varies the conditions sufficiently to separate the relative dependence on received noise level and distance from the source. To do this we will use two different environments with different sound propagation and include smaller array sizes in the study.

Variables that may affect the reactions of whales to seismic array are given in Table1, based on knowledge of whale behaviour and previous studies of noise effects on whales, particularly noise from seismic activity (see section B.2). In practice, we will not be able to cover all possible variables that might affect the results, and will focus on those that are most likely to be important based on existing knowledge. We expect that in the final results, we will be able to condense the effects to dependence on a relatively small number of dominant factors.

Variable that may have an effect	**How to obtain a range of values**
Received noise level	Vary distance and array size
Acoustical characteristics of noise e.g. spectral shape (distribution of energy across the frequency band) of the received noise	Vary propagation across two environments and array size
Variation in transmitted level e.g. during ramp-up	Vary array size
Distance from the air gun array	Vary array size, propagation
Relative movement of the air gun track to the whale (e.g. approaching, receding)	Will vary as whale paths cover a wide range of bearings. Use two array tow tracks
Relative direction of the air gun track to the whale track (e.g. will the tracks intercept – collision)	As above
Social category of whale (male, female, singer, mother with calf)	Varies normally at the study sites
Behaviour of whale (lone, interacting with others, surface active)	Varies normally at the study sites
Vocal state (singing, producing social sounds)	Varies normally at the study sites
Presence of other vocalizing whales	Varies normally at the study sites
Distance to nearby whales	Varies normally at the study sites
Social category of nearby whales	Varies normally at the study sites
Other stimuli (e.g. vessels)	Vessels are infrequent enough to avoid them interfering with experimental exposure, but frequent enough to be tested
Ambient noise	Varies normally at the study sites
Depth of water	Each study site has variable depth and there is significant difference between the two study sites
Distance to coast	Whale tracks at the east coast site vary in distance to the coast, and significant difference between sites

Table B1. Variables that may affect the reactions of whales to seismic arrays and how a range of values will be obtained for these in the project.

Whales live in an acoustically dynamic environment. The distance at which a source is audible underwater varies by more than a factor of 10 as sound propagation conditions and ambient noise change (Cato, 2008). Ambient noise frequently varies over a range of 20 dB as a result of changes in weather, or biological activity, and this alone will vary the audible range of a source by typically a factor of 10. Whales show a wide range of behaviours, depending on many factors, such as their behavioural state, their social category (males, females), presence of other whales and vocalizing whales. Behavioural reactions to air guns must be separated from all these other behavioural reactions, in order to determine what is actually due to the air gun exposure. Then the way in which other variables have affected the reactions to the air gun array needs to be determined. This requires complex and difficult experiments, ones that will test the range of variables likely to affect the responses of the whales, while ensuring that sample sizes are sufficient to obtain statistically significant results.

The project therefore is more than a simple dose response study in which the dose is the received level of the noise from the source. Such a dose response would apply only to the conditions in which the response was measured. This project aims to determine what would in effect be a multivariate dose response in which the dose is made up of many factors such as the variables in Table 1. We might expect that some of these variables will dominate the response and as such, these are the ones that become most important in designing mitigation.

In an ideal experiment, all variables likely to affect the results are held constant except for the one that is being tested. This is possible in physical systems but generally not in biological systems which are more complex and control of many variables is not possible. We will therefore follow the traditional approach of taking a sample subject to the —*treatment*‖ (e.g. the presence of the air gun array), and comparing this with a sample of similar size without the treatment – the *"control."* This assumes that the control is representative of the treatment sample, apart from the treatment. In the experimental design we have considered the firing of the air guns as the treatment, so that the control requires the air guns to be towed without firing. The presence and movement of the air gun vessel may also cause reactions, so may be considered to be an additional treatment, so that a second control is required: observations in the absence of the air gun vessel.

The experimental design of this study will follow the "before, during, after" or "BDA" design incorporating various treatment effects, and build on that of many previous seismic and non-seismic studies (see section B.2). In order to ensure that samples sizes are adequate, results of previous studies have been used in power analysis to determine sample sizes needed for experiments. Statistical analysis will include Generalized Linear Mixed Models (GLMM) using multiple measures of behavioural response and spatial interaction. GLMMs will be developed which will incorporate the range of variables likely to affect the results. This will allow us to determine the effects of the different variables on the response.

In order to understand the effects of ramp-up in a way that will allow us to assess and effectiveness and the potential for improving the design, we need to determine the effects of its components as well as the effects of the full ramp-up. That would allow us to determine the relative value of the individual components, and thus what is it about ramp-up that is effective or ineffective. The response to the first stage, which is usually the firing of the smallest air gun in the array, is crucial. In addition, the ramp up from one stage to the next, causing a significant increase in noise level is an essential component. McCauley et al. (2003) found that in nine out of 16 trials of exposing migrating humpback whales to a 20 cu in air gun, large mostly single whales actually approached the air gun, coming into a distance of between 100 and 400 m and then turning away. Levels would have been as high as 179 dB re 1 μPa at 100 m. To be effective, reactions to ramp-up need to be avoidance. We cannot test every component because each would require a set of samples for each component, each being a separate treatment, and only a small number of treatments can be achieved at reasonable cost, because of the sample size required for each treatment (see section B.3.10). We have therefore chosen to trial the first stage (one air gun), four air guns, the ramp-up from one to four air guns, and the full ramp-up typical of a seismic survey. The final decision on just what combinations and air guns sizes to trial will be made in consultation with JIP experts. The east coast site is ideal for examining the detailed effects of the components of ramp-up.

The variation in the size of the air gun array from one air gun, four to the full seismic survey array provides a wide range in variation of noise levels as a function of distance from the array which will allow us to separate the effects of distance from those of received level. It will also allow us to separate the effects of acoustical characteristics such as relative energy at high and low frequency, since the different array configurations will result in noise with different frequency distributions.

Environmental regulation of impact of noise on marine mammals is usually concerned with "significant" impacts with varying interpretations of what is "significant", generally along the lines of more lasting biological effects. Since behavioural reactions can occur at relatively low received levels, some within the range of ambient noise and thus at great distances from a high level source, it is important in management to separate those reactions that have little consequence, e.g. the animal quickly returns to normal behaviour, from those that have more lasting effects. There is little information linking observed reactions of whales to the longer term biological impact of these reactions. An expert review by the US National Research Council (NRC 2005) highlighted the importance of this, noting that while the primary focus of the regulations of the U.S. Marine Mammal Protection Act are at the level of the individual, the basic goal of the Act is to maintain sustainable marine mammal populations. This review proposed a roadmap in which observable behavioural reactions may be linked to life functions, then to vital rates and eventually to population level effects: The Population Consequences of Acoustic Disturbance (PCAD) conceptual framework. It recognized that years of work will be required to accumulate data and develop models for this transfer function, as well as the next transfer function, that leads to vital rates. While this is clearly beyond the scope of a single study, there are methods we can use to infer and to model effects on life functions. We may be able to suggest effects at the population level, the final step, in a way that will be useful in management of seismic surveys.

We can, for example determine whether a behavioural change lies within the bounds of normal changes in behaviour. Humpback whales change their behaviour routinely in response to many acoustic stimuli, including the vocalizations of other whales, in ways that clearly have no long term adverse consequences for the whales (e.g. Tyack, 1982; Darling and Berube, 2000). If a behavioural change lies within the bounds of these "natural" or "normal" behavioural changes, it might reasonably be inferred that the behavioural change is not likely to have an effect on variables further along the PCAD framework. An exception might be in a population that is already stressed and at the limits of sustainable allostatic load. If the behavioural change lies outside the bounds of normal behaviour, it can be compared with changes in response to other stimuli that the population is likely to encounter such as the effect of a passing ship. High levels of ambient noise could be considered in this category, or as part of the normal environmental stimuli. Again the immediate and cumulative effects can be used to determine whether the change in behaviour is likely to have an effect outside that already experienced by the population. Cumulative effects can be modelled from knowledge of the expected exposure, both from seismic surveys and other stimuli likely to be encountered by the whales. This information will be useful in management to balance the impact of the seismic surveys and impacts from other stimuli. To the extent that the behavioural change exceeds the bounds of normal behaviour, the effect on life functions can be interpreted in terms of the function of that normal behaviour and the way that function will be affected. This is the approach that we propose to use.

Such an approach requires substantial information about the population dynamics, the biology, and the normal behaviour and the acoustics of the populations studied. In fact, much is known about these populations (about 57 journal papers and 35 reports). There is substantial information on many aspects of life history and biology such as birth rate, age to maturity available from the examinations of thousands of individuals of these populations at whaling stations during the 1952 to 1963 whaling period (Chittleborough, 1965). The migrations are also well known (Chittleborough, 1965; Dawbin, 1966; Dawbin, 1997). The population dynamics have been studied for many years (e.g. Bannister et al. 1985, 2001; Chittleborough, 1965; Bryden 1990; Noad et al., 2006, 2008; Noad and Dunlop, 2007, 2008; Paterson and Paterson, 1984, 1989; Paterson et al., 1994, 2001, 2004). There have been many studies of the acoustics and behaviour for both east and west coast populations and some studies of response to playback. The vocalizations have been studied for more than 25 years (e.g. Cato, 1984, 1991, Noad et al. 2000, Dunlop, 2007). There have been studies of the response of the west coast population to seismic air guns (McCauley et al, 1998, 2003). On the east coast, the broad scale behaviour has been studied of more than 3,000 whales as they passed through the study area, and fine scale behaviour of many of these, including vocalizations of more than 400 individuals and playback of non-seismic signals (Noad et al., 2004; Dunlop et al., 2007, 2008; Smith et al., 2008).

B.2 Background to the problem

Marine petroleum seismic exploration is a persistent and intense source of underwater noise which great whales encounter around the globe. Most developed nations require some form of mitigation measures for great whale encounters during seismic operations and these conditions apply to all activities conducted by their citizens anywhere in the world. There have been a number of studies of effects of seismic operations on whales (see below) but knowledge remains limited. Regulations may be expressed in terms of ―significant‖ effects on whales, usually implying lasting biological effects but there is little information on this available.

Hence, there is considerable uncertainty in the knowledge required to adequately manage impacts of seismic surveys on whales. This has implications for both the protection of whales and the cost of management and mitigation. There is uncertainty on whether the ramp-up or soft start used at the start of a survey as a mitigation measure is effective. In order to reduce these uncertainties, behavioural response studies are required to determine the reactions of whales to seismic arrays, and to infer the biological significance of the exposure. There needs to be experiments to understand how whales react to ramp-up to assess its effectiveness and to design improved mitigation measures.

This project aims to address these issues. Environmental regulation of impact of noise on marine mammals is usually concerned with ―significant‖ impacts with varying interpretations of what is ―significant‖. This project aims to make some inferences about the effects on life functions by comparing responses of whales to exposure with the substantial existing knowledge of the behaviour and function of the behaviour under a wide range of conditions in the absence of air guns use.

Some of the earliest pioneering studies to determine effects of oil and gas exploration on great whale behaviour (some using seismic air gun noise a test stimulus) were a series of experiments carried out by Malme et al. (1983, 1984, 1985 & 1986) on gray whales. This body of work used a typical "before, during and after" (BDA) experimental design and incorporated a comparison between control ("undisturbed") whales measured on non-experimental days and experimental ("disturbed") whales, where several experiments were carried out per day. A single 100 cu in air gun source was used as the test stimulus. Early experiments on migrating whales defined a predictable pattern of response (track deflection, decrease in speed and later a "probability of avoidance" measurement) as a function of received level using industry noise as a source (Malme et al. 1983, 1984). Further studies utilized this defined pattern of response to test the response of northward migrating mother-calf pairs to a stationary and towed single air gun (Malme et al. 1983). A predictable reaction was found in groups exposed to received levels of >160dB re1µPa and within 2 km of the source. Despite the small sample sizes, some behavioural changes were observed; changes in speed, direction of travel, increased likelihood of swimming into surf zone or a nearby sound shadow; but some these behavioural changes were found to be independent of proximity and received level. Southbound animals were found more inshore or further offshore when within 2 km from the source, though no response was detected with moving source (Malme et al. 1984). Similar experiments were carried on migrating bowhead whales (Richardson et al. 1985; 1986) using a single bolt air gun as the test stimulus. Both studies found similar behavioural responses. When exposed to strong seismic pulses (>160dB), both bowhead and grey whales tended to have shorter surfacings and dives and fewer blows per surfacing compared to undisturbed whales. This response was noted as a common pattern of behavioural change in whales disturbed by human activities. Richardson et al. (1995) summarize the results of a number of studies that gray and bowhead whales generally avoided seismic vessels when the received levels were in the range 150 – 180 dB re 1 μPa. McCauley et al. (2003) found avoidance reactions by migrating humpback whales at levels between 157 and 164 dB re 1 μPa, but females and calves resting during the migration in a large bay, the mean avoidance level was 140 dB re 1 μPa.

Many early studies aimed to determine if seismic exploration activity caused disturbance in great whale feeding behaviour, defined by cessation of feeding (and change to another behaviour such as travelling), movements out of the feeding area or changes in the distribution of feeding groups. Malme et al. (1986) found that gray whales exposed to seismic were more likely to travel away from the source (stop feeding) compared to drill ship noise playback. However, due to small sample sizes, there was not enough data to compare frequency of these behaviours between control and exposed groups to seismic. The general conclusion from this study was that there was a 50% probability that gray whales stop feeding and move away when received level reached 173dB re1μPa and a 10% probability at 163dB re1μPa. However, gray whales returned and resumed feeding after air guns were gone. Studies on other great whale species found similar results. A general shift from feeding to travelling was found in bowhead whales exposed to seismic air guns (Ljungblad et al. 1985), though Wursig et al. (1999), using a full seismic array as a source, found no change in distribution of feeding gray whales. In the latter study, other broad scale parameters (population, reproductive success, body condition) were compared between exposed and non-exposed years to a full seismic survey and no significant differences were found (Wursig et al. 2002, 2003). Other studies examined specific avoidance behaviours in feeding whales. For example, feeding humpback whales exposed to a single 100 cu in air gun showed no avoidance pattern up to 172 dB re1μPa received level (Malme 1985) even though, on a small number of occasions, a startle response at air gun onset was noted (received level of 150 – 169 dB re1μPa at ranges up to 3km from source).

These early studies used relatively simple experimental designs and highlighted problems with low sample sizes equating to low experimental power and short experiments. Simple statistical analysis was used to test between “control” (non-exposed) and “exposed” (experimental) whales and, if the sample size allowed, between BDA experimental periods. An appropriate “before” period provides the behaviour of whales prior to exposure to the stimulus to allow some comparison of behaviour to be made “during” and “after” exposure. In the Malme experiments, a number of exposures were carried out each day. Therefore, whales analysed in subsequent experiments could not be viewed as “undisturbed” during the “before” period. Additionally, behaviours such as “length of blow interval”, “surface interval”, “dive time” or “number of blows per surfacing” are measured repeatedly on one individual and therefore the data may be auto correlated. In other words, serial measurements are taken on an individual over time and these measurements may be highly correlated, artificially reducing variance. The Malme papers did not address any serial dependence issues. The Richardson papers acknowledged this may be a problem but did not account for serial dependence of the data due to analysis complexity. Furthermore, the effect of the vessel was not accounted for. Before conclusions can be made on the response of whales to a seismic stimulus, adequate controls must be carried out to eliminate all other possible factors that contribute to the response, for example, the presence of the vessel.

An improvement in modelling techniques over the years and the development of more sophisticated statistical analysis packages have allowed more complex analysis of data to be carried out and therefore some of the analysis issues can be addressed. Modelling techniques can also incorporate other environmental effects that may influence the response of whales to noise from air guns. Recent studies testing the effect of a full seismic survey on feeding behaviour in gray whales (measured by the frequency of visible mud plumes from bottom feeding; Yazvenko et al. 2007) and general abundance, behaviour and movement (Gailey et al. 2006), used modelling techniques which allowed the incorporation of environmental variables into the analysis. Results of both experiments suggested that there no measureable effect on measured gray whale activities as a result of the seismic air gun survey. Both experiments did not account for the non-independence of samples in their analysis model (where whales were probably repeatedly sampled between experimental conditions such as "guns off", "post-seismic", "strong seismic" or "weak seismic") and adequate controls were not carried out. Therefore any subtle effects of the seismic survey were probably lost. The Yazvenko experiment in particular noted high variability in feeding activity index (the index used as to equate feeding activity of whales in the area) and therefore admitted low experimental power.

One way to account for high variability within the response variable being tested is to incorporate a random effect in the statistical model. This random effect accounts for the "within group" variance from randomly selecting a small number of test subjects from a large population. It also accounts for repeated measurements within the dataset where test subjects are measured before, during and after the stimulus. Testing for autocovariance (and accounting for this in the analysis) also eliminates problems with non-dependence of continuous data collected on an individual. Miller et al. 2009 used this approach when analysing the response of sperm whales to a full seismic array. The exposure regime consisted of ramp-up followed by 1 – 2 hr. exposure. In this study only eight whales were measured during five experiments (with a number of non-exposed control groups) but it was the first to use digital recording tags (DTAGs) as a way of recording fine scale continuous behaviours (3D movements of the tagged whale and sound field). Sound exposure varies widely between depth (surface v diving whale), range and habitat and the DTAGs provide a way to determine received levels at the tagged animal (Madsen et al. 2006). However, this study encountered a number of problems due to the logistics of designing such a complex experiment at sea. Firstly, two different arrays were used in the two experimental years but this difference was not accounted for in the analysis (due to small sample sizes). Secondly, up to three whales were tagged during one experiment which may pose problems with non-independence of samples where test subjects may interact with each other and therefore cannot be called independent samples. Thirdly, there was a possible sampling bias towards less sensitive whales that were easier to tag and fourthly, there were no "controls" to account for the presence of the vessel. Most of the analysis focused on comparing the behaviour of tagged whales before, during and after exposure but due to the small sample size and therefore low experimental power, only preliminary conclusions could be made. Behavioural changes included possible horizontal avoidance, fewer pitching rates during diving, lower but not significantly lower buzz rates (used as a proxy for attempts to capture prey). No change in broad scale changes in behavioural state (resting, foraging) were found therefore whales tended to exhibit subtle changes in behaviour rather than clear avoidance.

One of the most common problems in many "playback" or "controlled exposure experiments" comes from Pseudoreplication. The term "Pseudoreplication" covers a specific range of experimental errors in which the sample size (n) used in a particular statistical test is not sufficient to test the hypothesis (McGregor, 2000). One of the most common errors is that the experimental design is a "before, during, after" (BDA) design in which the subject is monitored before, during and after presentation of a stimulus. The analysis of data wrongly treats subjects within each BDA period as independent samples rather than a repeated measures design. Further Pseudoreplication errors occur from a number of different sources; a subject may be repeatedly presented with more than one stimulus but the order of effects is not taken into account therefore replicates are wrongly treated as a number of independent samples. Subjects may interact biologically within an experiment (which relates to internal validity errors) and therefore samples are once again not independent, though are treated as independent samples in the analysis. A number of different recordings of a particular stimulus may be used within the experiment but the analysis wrongly pools the replicates and treats these multiple recordings as one treatment. Finally, conclusions may be wrongly drawn about the function of, or response elicited by, a specific stimulus without true replication of the experiment. In other words, the true sample size of the experiment is one, but experimenter wrongly interprets the sample size as the number of trials or replicates used in the experiment. Invalid conclusions are then made about how applicable the result is to the population or species.

The proposed experimental protocol incorporates a "BDA" design (before, during, after) with comparing exposed groups (air guns on, vessel moving in a pre-determined direction relative to the target group) with adequate "control" groups (air guns off, vessel moving along the same pathway and non-exposed, migrating groups with no air gun vessel in the area). Independent group sampling will be carried out to ensure internal validity, and any multiple groups sampling will ensure that "nearest neighbour" and other group effects are taken into consideration. A power analysis will be performed after each experimental year to ensure that the appropriate samples are collected for each treatment. Statistical analysis of the results will use appropriate models which will account for the repeated measures design, allow for any autocovariance in the data and will include all fixed (for example, the presence of the air gun stimulus, type of air gun array, tow-path with the inclusion of social and environmental variables), continuous (proximity to the source, received level) and random effects (within-group variation) into the analysis, which goes beyond a simple dose-response model. The use of DTAGs will allow for a more fine-scale analysis of the response (as in Miller et al. 2009), but the inclusion of the focal follow and scan sampling platforms of observation will increase the experimental sample size and allow for a more integrated approach to the analysis. Two different populations will be studied (allowing more general conclusions to be made about the response of humpbacks to air gun stimuli and predictions of responses in other populations), a number of different array configurations will be used and experiments will be performed over a number of years, allowing the experiment to be replicated and therefore overcome problems with external validity.

B.3 The technical approach, including any constraints

B.3.1 Australian humpback whales

Humpback whales migrate annually for thousands of kilometres along the east and west coasts of Australia, between their summer feeding grounds in the Antarctic and their winter breeding grounds in tropical waters (Chittleborough, 1965; Dawbin, 1966). A diagrammatic representation of the migration paths is shown in Figure 1, together with the proposed study sites. The populations off the two coasts area largely separate with only a small amount of interchange (Chittleborough, 1965).The breeding grounds are diverse, covering the large area within the Great Barrier Reef in the east and an even larger area over the Northwest Shelf in the west. The migration paths converge at the points where the coasts protrudes most to seaward, concentrating the whales near the coasts, and providing the most reliable opportunity to encounter whales. Hence the study sites are in these areas, and these are where most previous studies of humpback whales in Australia waters have been located.

The study sites are somewhat south of the breeding grounds. Since humpback whale calves are usually born in the tropical breeding grounds, pregnant females pass through the study areas during the northbound migration (June to August) and new born calves during the later part of the southbound migration which extends from August to November. The proposed experiments will be during the southbound migration.

Both east and west coast populations were substantially depleted during the whaling period from 1952 to 1963, but have shown a remarkable recovery. It is estimated that the east coast population size would have been of the order 100 at the end of whaling (Paterson et al., 1994), whereas today the population size is estimated to be more than 12,000 (extrapolating from Noad et al., 2008). This population has shown a consistent rate of increase of 10.5 to 10.9% over many years (Paterson et al., 2003; Noad et al., 2006, 2008). The west coast population size is larger and is currently estimated to be about 22,000 (Hedley et al., 2009).

The timings of the migrations are remarkably consistent, showing little variation from year to year (see Paterson et al., 1994; 2001 for timing of migration past Brisbane, near the east coast site – most whales pass within an eight week period with little variation). Hence we can reliably choose the timing of our experiments based on many years of consistent patterns in the migration. About half the population passes in the four weeks at the peak of the migration, so that on average about 90 whales can be expected to pass the east coast study site over the 10 h period of observation each day. Higher numbers are expected off the west coast where the population is significantly larger, though spread over a larger area.

Humpback whales were chosen for this study as exemplars for baleen whales for a number of reasons. Many humpback whale populations worldwide spend some time near shore during migrations or breeding and this is likely to bring them in contact with human activity. In Australian waters, they are the whales most likely to be encountered during seismic operations. They are very vocal and their vocalizations overlap in frequency with the sounds of seismic air guns, so their acoustic communication may be affected by the noise of seismic surveys. The regularity of the timing, and the proximity to shore of their migrations allow better structured and controlled experimental designs for BRSs that would be possible with most other species of baleen whale. For the populations to be studied in this proposal, there is also substantial knowledge about their vocalizations and normal behaviour, which provides the context for interpreting the results.

B.3.2 Experimental sites.

This study will consist of experiments and observations at two field sites, one inshore on the east Australian coast north of Brisbane (termed the “inshore” site) and the other offshore off the west Australian coast in the Exmouth region (termed the “offshore” site). The proposed time frame of experiments is shown on Table B..2, while the general locations of the two sites are shown on Figure 1. Each site has advantages and limitations, but together will allow us to perform a comprehensive suite of experiments to address the aims of this study.

Experiment	**Time frame**	**Site (number of field days)**[1]	**Purpose**
1	Sep-Oct 2010	Inshore - East Australia (28)	First experiments including propagation measurements and baseline behavioural observations; BRS using a single air gun, 2 tow paths.
2	Sep-Oct 2011	Inshore - East Australia (42)	Small air gun array and ramp-up BRS using 1 to 4 or 5 air guns; collection of baseline data on normal behaviour continued.
3	[2]Sep-Oct 2012	Offshore - West Australia (22)	Repeat of components of small array experiments as used in Experiments #1 and #2 to compare with the east coast results
4	[2]Sep-Oct 2013	Offshore - West Australia (35)	Full array exposure experiments using ramp-up and normal survey operations

Table B.2: Timeline for the proposed experiments.

Notes:

1 These are the number of days of experimental work in the field and do not include the setting up and winding down

2 Experiments #3and #4 can be interchanged between 2012 and 2013, depending on the availability of full seismic array.

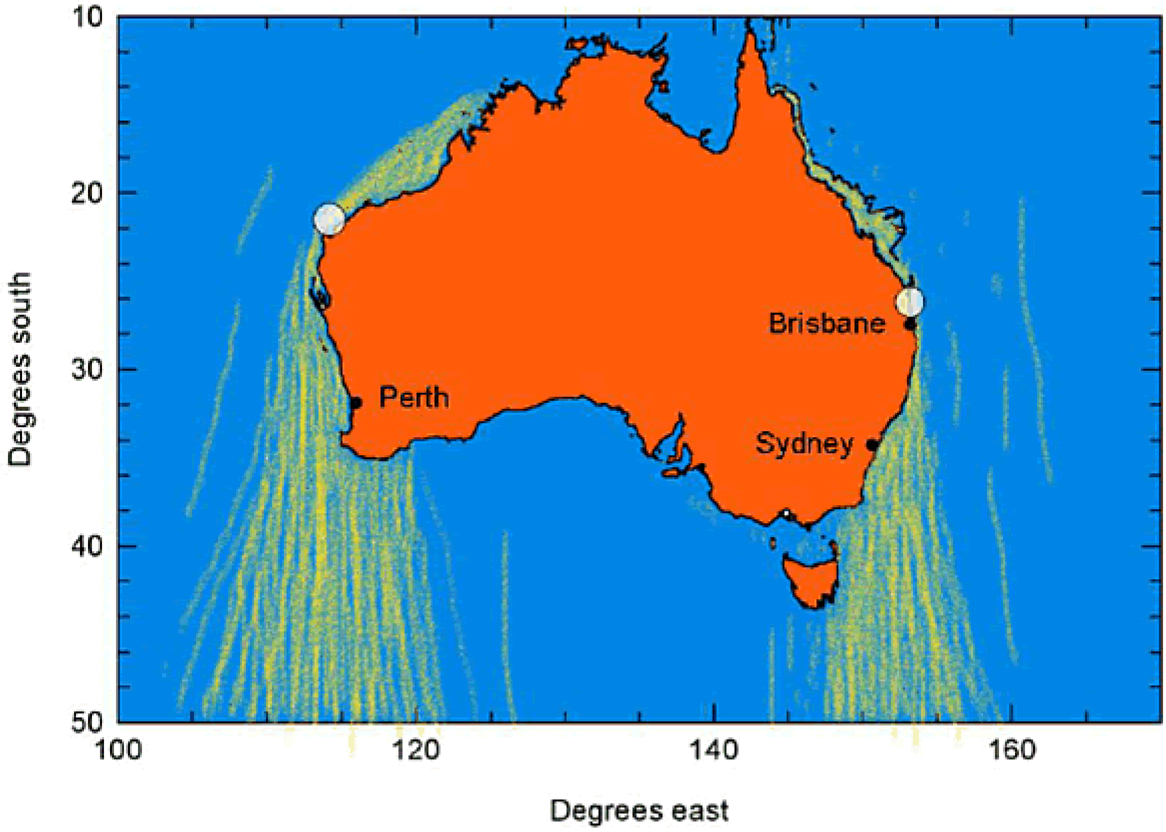


Figure 1: Study regions (circles) around Peregian Beach on the east coast and Exmouth on the west coast, with diagrammatic representation of humpback whale migration paths.

B.3.3 Experimental program

Experiments are planned to take place during the southward migration of humpback whales in September and October for several reasons: (1) peak numbers of whales migrate inshore past the field sites during this time; (2) behavioural observations will be directly comparable to large data sets collected previously; (3) high numbers of calves are present allowing us to study female-calf groups which are generally considered to be the most vulnerable to disturbance from anthropogenic noise and (4) show behaviour that is a combination of breeding, social interaction, and surface active behaviour, as well as migration. The consistency in the timing of the migration ensures that there will be more than enough whales passing through the sites for the experiment to be effective. For example, we expect to have, on average, about 90 whales passing through the east coast site in the 10 h of each day‘s experiment.

The single air gun work in Experiment #1 in 2010 will be used to develop an empirical propagation model for the east coast site, obtain the data for the single air gun and the results will be used to fine tune the experimental design. The design of each subsequent experiment series will be fine-tuned using the results of the previous experiments. Hence procedures given below are expected to change as the project progresses. Table B..3 lists the timing of the different experiment series, while Table B.4 lists the planned experimental exposure types.

Year	Experiment #	Components of ramp-up experiments	Full array experiments	Tow paths
2010	1	E10: exposure #1		2
2011	2	E11: exposure #2, #3		1 or 2*
2012	3	W12: exposure #1, #3		1
2013	4		W13: exposure #4	2

Table B.3: Timing of experiments. Experiment code: is E is east coast, W is west coast followed by the year. Experiments will be conducted in September and October during the humpback whale south bound migration. Exposures are given in Table B.4. Tow paths are nominally across the migration and oblique to the migration. Note that depending on the year of availability of a full sized commercial air gun array the west coast experiments may be switched between the years indicated. *The number of tow paths used in Experiment #2 will depend on the time available. If the experiments go according to plan, with few setbacks, a second tow path should be possible.

Exposure type #	Number of air guns used	Firing sequence
1	1	Repeat at typical survey rate
2	4*	Repeat at typical survey rate
3	4*	Ramp-up from 1 to 4 air guns
4	Full array	Ramp-up followed by full operation as in typical survey

Table B.4: Exposure types

***The choice of the number of air guns and their sizes has yet to be decided and will require feedback from JIP experts.**

There will be three types of exposure treatment with air guns firing at a rate typical of survey:

i. Exposure #1 will involve a single air gun on two tow paths relative to the migratory stream: one across (at right angle) and one oblique (at 45° to the direction of the migration);
ii. Exposure #2 will involve four air guns towed one of the paths used for exposure #1, to be determine from the results of Experiment #1;
iii. Exposure #3 will be ramp-up using the four air guns on same tow path used in exposure #2, but if we have time we will do this on both tow paths. We have planned the experiments according to our expectations of what can be achieved based on previous work, and if things go well it should be possible to complete this second tow path. However, difficulties can always be expected in working at sea, so there are limits to how well we can predict what we will achieve, so have been conservative in our prediction.

Experiment #1: inshore site, 2010.

The 2010 study will set the initial experimental design and data collection protocols for both sites. It will use one air gun (we have a 20 cu in size available, but the actual size used will be determined in consultation with JIP experts). It will also include measurement of air gun propagation loss at the site and propagation modelling to allow received sound levels to be calculated for the other components of ramp-up to be used. Propagation measurements are not required off the west coast as the authors have multiple data sets of commercial and experimental single air guns and air gun arrays.

As well as providing the results for exposure #1 (Tables B.3 and B.4) These measurements are required to plan the detail of the experiments using the four air gun array off the east (exposures #2 and #3), in terms of logistics and layout and to set the experimental design and data collection protocols. Because of the proximity to shore, caution is required in exposure of whales close to shore and the results of this study in conjunction with behavioural data from single air gun exposures (#1) will aid in designing the experimental procedures to adequately manage the impact.

Experiment #2: east coast 2011 & Experiment #3: west coast 2012 - components of ramp-up.

Experiments #2 and #3 will use a four air gun array in two exposures: all four together and ramp-up through the four air guns. The east coast experiments will be used to develop a statistical model for responses. The model will be tested using exposures #1 and #3 in the 2012 experiments on the west coast to establish a strong statistical link between the two study sites in preparation for up-scaling the work to a full commercial array. Sufficient experiments will be conducted with each exposure to obtain an adequate sample size (see sections *B.3.6* and *B.3.8*).

We have allowed a contingency in case not all the work planned in 2010 is completed. The difficulties of working at sea mean that there are likely to be some setbacks in the first experiment. If things go well, however, and this contingency is not needed, we should be able to complete a second tow path with one air gun treatment (say ramp-up to four air guns).

While we have nominally chosen to use a four air gun array in exposures #2 and #3 (in Experiments #2 and #3), the number and capacity of the air guns used for will depend on the results of our single air gun work and the propagation model generated in 2010 as well as feedback from JIP experts. We will use the maximum number and capacity of air guns that we consider safe in terms of impact on the whales, based on the limitations of the sites and how the whales respond.

Full array experiments (offshore site only) – experiment #4, 2013.
A full commercial array will be used in these experiments. The exposure will be ramp-up typical of a survey followed by normal operation of the array. There will be two tow paths, nominally one across the migrations stream and one oblique (at 45° to the direction of the migration). The actual paths will be decided in conjunction with stakeholders using the results of Experiments #1 to #3. Note that this experiment could interchange with Experiment #3 and be done in 2012, depending on availability of a suitable vessel and array.

Comments.
Details of the sampling protocols and observational techniques are given in following sections.

Most experiments will be conducted with whales that have not been exposed to air gun sounds for at least some weeks before. The rate of migration ensures that whales will be far enough north on the day before they are in the study area for the received sounds to be so low that these whales can be considered to have had no recent previous exposure. It will be possible to conduct a control study in the morning and a treatment study in the afternoon on some experimental days for all except the full array work (Experiment #4) . In case there is an effect of time of day, some controls will also be conducted in the afternoon with no treatment studies in the morning, and some treatment studies in the morning without controls in the afternoon. Although focal groups will be designated, other whales will also be tracked and behavioural observations made. Other migrating whale groups will be tracked between experiments. Mother-calf and mother-calf-escort groups will be targeted as these are expected to be the most sensitive to noise exposure and the most common social groups.

The study of McCauley et al (2003) inside Exmouth Gulf using a single 20 cu in air gun in BRS experiments with humpback whales showed that some whales approached the air gun. In more than half of 16 BRS‘s large, single animals approached directly towards the air gun often at high speed, some up to eight knots. It was hypothesized that these were males and that they were attracted to the air gun because of the similarity of the air gun sound to the sound of a breaching whale. In the experiments planned here we will station a team of whale observers on the air gun vessel with suitable tracking equipment to enable rapid and fine scale whale movement patterns near the air gun vessel to be established, plus will target biopsy samples during air gun operations to determine these whale‘s sex.

B.3.4 Special observational equipment and techniques

Three specialized observational systems that will be used extensively throughout the experiments are described briefly below and in more detail in B.6 "Availability of unique facilities".

Cyclops software. [1]
Cyclops provides a computer based multilayered map display of whale and vessel positions, derived from theodolite, acoustic and other tracking, and annotated with observed behaviours. It was developed by co-investigator Dr Eric Kniest (University of Newcastle) and tailor made for the types of experiments proposed. Operation is effectively real time and it can be run on computers on the various operational platforms used in experiments, merging all data by continual updating by wireless link within wireless range. Cyclops will be used on all the proposed experiments to record and display data and it will be used extensively in the later detailed analysis.

[1] Cyclops, or Cyclops Tracker has been renamed VADAR (Visual and Acoustic Detection and Ranging)

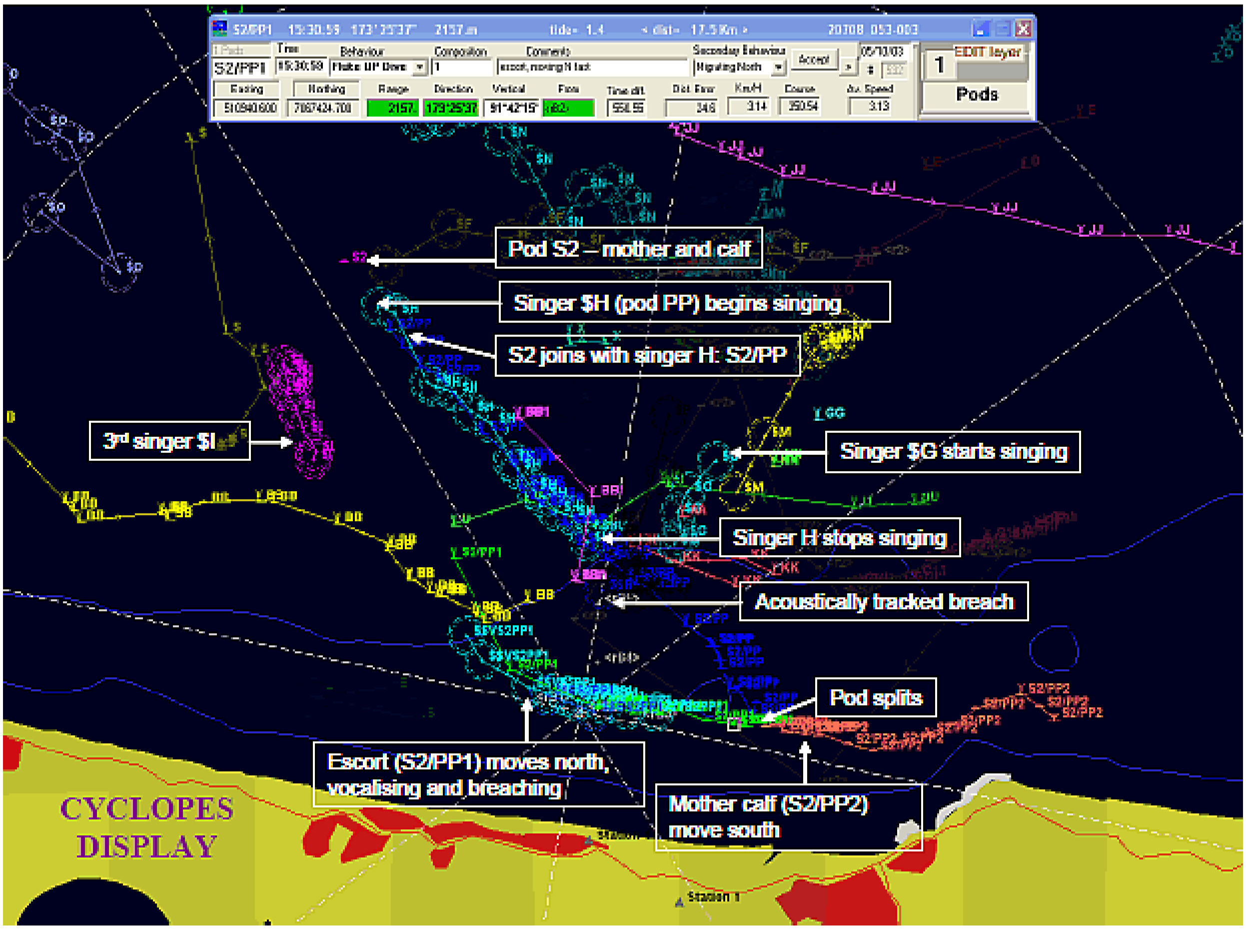


Figure 2. Example of the *Cyclops* display from a day during the HARC experiments at the east coast site, showing tracks of whales and behaviour over a period of hours. It is oriented with east upwards. "Station 1" near the centre at the bottom of the display is the theodolite position. The dashed lines radiate from the centre of the hydrophone array. The dashed arcs in the upper left and right hand corners are 10 km radius from this centre. Whale groups or pods are labelled starting from A each day, singers have the prefix $, behaviours such as blows are indicated by icons. Acoustic positions include estimates of uncertainty. Boxed annotations in white have been added to explain some of the activity recorded.

Theodolite position fixing is calculated by *Cyclops* on a computer connected to the theodolite. Acoustic position fixing is determined using *Ishmael* software (Mellinger, 2001) with hyperbolic localization from time of arrival differences to the hydrophones. The *Ishmael* file is then read by *Cyclops*. Figure 2 shows an example of the display, for a day during the Humpback Whale Acoustic Research Collaboration (HARC[2]) experiments at the east coast site with a theodolite on a 73 m high hill and with acoustic data from five hydrophone transmitter buoys described below. The boxed comments in white have been added.

Visual position fixing.

Theodolites will be used on the east coast to determine whale positions from the horizontal bearing and the range determined from the angle to the horizon, as has been used in many whale observation experiments. An additional technique that has been successfully trailed uses a digital camera with compass. A photograph of a whale with the horizon visible allows the angle to the horizon to be measured and with calibration of the camera lens, to determine the range. This will

[2] The Humpback Whale Research Collaboration, funded mainly by the Office of Naval Research, involved Scripps Institution of Oceanography, Wood Hole Oceanographic Institution and the University of St. Andrews Scotland, as well as Australian researchers. The proposed east coast experimental techniques were developed and trialled at the Peregian site during this project.

be suitable for use in vessels where the use of a theodolite is impractical. In addition, an inverted sextant will also be used in vessels to obtain the angle to the horizon. These techniques are useful in the larger vessels to be used where sufficient height above the water is available.

Acoustic loggers.
The CMST-DSTO acoustic loggers are autonomous moored acoustic recording systems that can be left for months at a time to record underwater sounds. The design is very flexible allowing short or long term deployment, with variable sampling regimes. Multiple loggers can be used for position fixing of sound sources using hyperbolic methods (e.g. by *Ishmael*). Timing accuracy between loggers is provided by quartz clocks and daily transmission of pinger signals between loggers. The loggers are fully calibrated to give absolute sound levels in the water and can handle a very wide range of signal levels through use of multiple recording gains and signal conditioning. For example, they can record low levels of background sea noise to high levels from close seismic arrays (e.g. directly underneath 3040 and 2390 cu in arrays) without signal clipping.

The acoustic loggers will be used at many positions at both sites to record the acoustic field from background noise, whale vocalizations and air gun signals.

Moored hydrophone and transmitter buoys.
These can be moored for months and continuously transmit acoustic data recorded from attached hydrophones via VHF radio link to shore base stations. They were developed by DSTO and the University of Queensland and have been used extensively throughout the HARC experiments for acoustic tracking. They are designed to keep the transmitter antenna vertical while the buoy moves with the waves.

Five systems were used in HARC in a T shape with about 750 m spacing between adjacent hydrophones and these provided the acoustic data to *Ishmael* and *Cyclops* for tracking acoustic sources. The hydrophone positions can be very accurately determined by theodolite, allowing accurate acoustic localization. These systems are fully calibrated to give absolute sound levels in the water and were used for this purpose as well as for acoustic tracking during HARC. The systems will be used in a similar manner in the proposed experiments.

Tags attached to whales.
Both digital recording tags such as DTAGs and satellite tags will be used in the experiments. DTAGs attach to the whale with suction caps and record the received sound field, the three dimensional motion of the whale and the dive profile. They detach from the whale at a pre-set time and need to be retrieved, using a radio transmitter to indicate their position. We have used DTAGs on previous experiments off the east coast with a high success rate, and they provide a large amount of useful data. Attachment time is usually several hours. For the proposed experiments, we would like to include tags that last for significantly longer periods before detachment in order to obtain a long time history of behaviour and movements, to test how long it takes for the whales to return to normal. Tag technology is developing and it will be a matter of choosing the most appropriate tags at the time of the experiment. Satellite tags are implanted in the whale and remain attached for much longer than DATGs. They provide the tracks of the whales and future developments may include dive data.

B.3.5 Experimental design.

Experiments will follow the “before, during and after” (BDA) design. “Exposure” experiments (air gun firing) will consist of a number of different treatments in the “during” phase (Table B.4).

"Control" experiments will consist of the air guns in place but not firing in the "during" phase. BDA periods in "non-exposure" experiments (no air gun vessel in the area) will last for a comparable time to "exposure" and "control" experiments.

A difficulty with playback or BRS experiments is one of avoiding Pseudoreplication (Hulbert 1984; McGregor et al, 1992; McGregor, 2000), in which either the stimulus is not representative (i.e. a true replicate) of the class of stimuli or the subject animals are not representative of the class or animals to which they belong. For example, the use of the same air gun array for all experiments will provide information about the response to that particular array, but not to air gun arrays in general. In the worst case, if there is something peculiar about that array and towing ship not found with other arrays or towing ships, the peculiarity might be the dominant factor in causing the response. In a review of playback studies with marine mammals, Deeke (2006) found that only 17 of the 46 studies reviewed avoided Pseudoreplication. We plan to use a range of stimuli of different scales (Table B.3) and in two different acoustic environments to avoid Pseudoreplication of the stimuli. Generally it is easier to avoid Pseudoreplication of the subject animals by choosing many independent individuals as subjects of exposure. We are able to do this with many whales passing through the study sites, and the nature of the migration ensures that individuals have not been previously exposed to the stimulus during the current migration. There is some cost in avoiding Pseudoreplication in that it increases the sample size required.

Before phase.
Since the whales will be migrating southward, observations will commence north of the air gun source by selecting one or two focal groups of whales and following these as they move south. This will provide "before" observations. The focal groups will be tagged with recording devices such as DTAGs and satellite tags 5 to 10 km north of the air gun array on the east coast (inshore site) and at similar distance and also between 10 and 50 km north off the west coast (offshore site). Allowance will be made for whales to return to normal behaviour after tagging. Pre-exposure observations will continue for one hour and will terminate when the whales are in position for the "during" phase.

At the inshore site, most whales passing through the site will be tracked using a theodolite scan sampling. Behavioural observations of focal whales (focal follows‖) will be made using two additional theodolites, one each per focal follow and there will also be observations from a following boat. Vocalizing whales will be tracked using an array of five moored hydrophone buoys. At the offshore site, focal whales will be followed from one of three or four vessels (a large support vessel with a 7 m height of eye plus two offshore capable small vessels which will also be used for tag and biopsy work). At each site a whale observation team will be located as high as possible on the air gun vessel to monitor movements and behaviour of all whales in the vessel vicinity at all times (irrespective of state of air guns).

Acoustic recordings will be made at many positions throughout the study areas using moored autonomous recorders. These will comprise CMST-DSTO sea noise loggers deployed with the hydrophone on the seafloor, with units set individually or in a tracking configuration using 1-2 km hydrophone spacing. Some moorings may remain *in situ* for an entire experimental period, and recovered using acoustic releases. Others will be deployed with surface floats as required. All CMST-DSTO sea noise loggers will be set with multiple gains so as to span the highest expected air gun signal levels and normal ambient sea noise across the bandwidth 1-5000 Hz. One or two drifting sea noise loggers will also be set with multiple hydrophones located through the water column to sample the vertical sound field produced by the experimental air gun. Data will be recovered from the autonomous systems on recovery, while the moored array will send data to the base station via radio link for real time tracking. These recordings will allow the acoustic field received by whales throughout the study areas to be determined for all sources including the air guns, other individual sources (e.g. ships and singing whales) and ambient noise. The acoustic equipment will allow singing whales to be tracked at each site.

During Phase.
The "during" phase will include three different types of trial or treatment, with similar observations for each:

1) "exposure" (air guns firing depending on exposure type)(Table B.4),
2) "control" (air guns towed by vessel but not firing)
3) "non-exposure" (no air gun vessel in the area).

Both "exposure and "control" experiments involve the vessel towing the air guns moving across (nominally at right angles) to the general migration direction or obliquely (about 45°) to the direction. Air gun operations will commence after the focal groups have been observed for about 1 h or more in the "before" period and are about 3 km north of the track of the vessel for exposures #1 to #3. For the full commercial array exposure #4, there will be an additional focal group selected at a distance between 30and 50 km NE (upstream of the migration). The air gun start will be delayed if there are whales within 500 m of the air guns, and exposure will be suspended if a mother-calf pair comes within 500 m or within a radius where the estimated SEL exceeds 160 dB re 1μPa^2.s. The air gun exposure will continue for 1 h for exposure types #1 to #3. For the full commercial array, the exposure (after the initial ramp-up) will continue for a longer period, nominally 7 – 10 h (see section discussion on Experiment #4 in B.3.7 h for more details). The air gun vessel will maintain a set course specified before the experiment begins and will not pursue whales or make major course deviations during an experiment.

The air gun start time will be nominal within a 15-20 minute window and decided by the experiment controller who will also decide whether the run should be an exposure (guns firing) or control (guns towed but not firing) and the air gun status (on or off). In an attempt to keep the observers "blind" to the treatment (i.e. exposure or control) the observers will not be informed.

For the control, the vessel will tow the array without the guns firing and observations will be made as above. For the "non-exposure" (no air gun vessel), similar observations will be made.

Permits may require shut down of air guns if certain conditions or effects are observed.

After phase.
For Experiments #1 - #3 (components of ramp-up), this commences when the air guns cease firing, which will again be within a nominal 15 minute window, or immediately if a permit trigger is reached. Observations will continue, as above, for at least 1 h until limited by logistical considerations (for example, the groups have moved out of visual range). For Experiment #4, the full array, the "after" phase is not clearly defined, since the array will continue operation for some hours and whale behaviour may return to normal in this period (see discussion on Experiment #4 in B.3.7 h for more details).

Tag retrieval and biopsy collection.
A small offshore capable vessel will move in to collect biopsies from focal whales and continue to follow whales until any tags designed to detach, release and can be recovered.

Comments
Although focal target groups will be primarily followed, as many other whales as possibly can be followed will also be tracked and behavioural observations made of these also.

B.3.6 Details of East Australian experiments

The east Australian experiments will all take place at Peregian Beach, which lies 130 km north of Brisbane on the Sunshine Coast (Figure 3). Previous studies known as HARC, the Humpback Whale Acoustic Research Collaboration, have been conducted at this site in 2002, 2003, 2004 and 2008 (Noad et al., 2004; Thode et al., 2004, 2006; Dunlop et al., 2007, 2008; Noad and Cato, 2007; Smith et al, (2008).

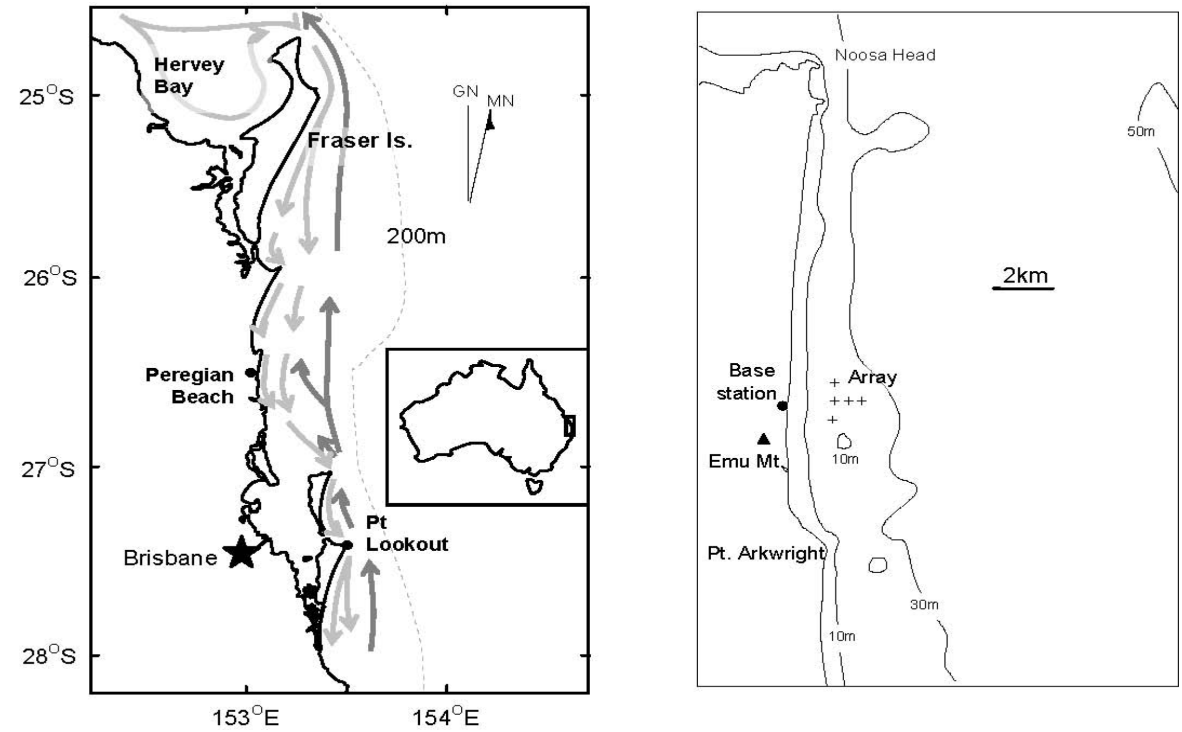


Figure 3: Location of east coast study site at Peregian Beach. Left south eastern Queensland showing Peregian relative to Brisbane and the migratory routes of the humpbacks. Right – detail of the Peregian study site with the observation hill (Mt. Emu) and the approximate location of the passive acoustic tracking array with receivers shown as +. Acoustic data are received at the Base Station by radio link and visual and acoustic tracks and behavioural data on *Cyclops* are interchanged between computers by wireless link.

The site consists of a long, continuous beach with a gently shoaling bathymetry providing reasonably even propagation of sound to the north and east. Emu Mt, a 73m high hill, lies approximately 700m inland of the beach and provides an observation platform (Figure 3). Fine scale bathymetry of the site was mapped in 2004 (broader scale bathymetry is also available from Geosciences Australia). Most whales pass within 10 km of the beach.

Experiment #1

This will be undertaken in October and November 2010 and will use a single air gun on two tow paths, one moving across (nominally at right angles) to the general migration direction or obliquely (about 45°) to the direction.

The detailed aims are to:

(1) observed the reactions of whales to a single air gun on two tow paths and measure the variables likely to affect reactions,
(2) measure propagation loss as a function of distance throughout the site, and to develop a propagation model for the area

(3) refine the data collection protocols for all experiments.

A single air gun will be used on the two tow paths. We have a 20 cu in, Bolt 600-B air gun (at Curtin University) but the actual size used with depend on advice from JIP experts. It will be deployed from a suitable vessel (19 m fishing vessel currently under consideration). During air gun propagation measurements, autonomous bottom-mounted acoustic recorders (CMST design) will be deployed through the study area along with hydrophones deployed from vessels, moored hydrophone buoys and one or more drifting noise loggers set with multiple hydrophones spaced vertically through the water column. CTD casts (Sea-bird 911) will be made to measure sound speed through the water column. Air gun source levels will be measured using a reference hydrophone located on the air gun towfish. All hydrophones will be calibrated and at the start of recordings, systems will be calibrated using white noise of known level input. Acoustic recordings will be sampled at 20 kHz. A hydrophone deployed near the air gun will be used to determine the source level.

The seabed acoustics will be estimated by geo-acoustic inversion of propagation loss derived from the known source level for each shot and the appropriate measured air gun signal.

Experiment #2

This will occur during September and October 2011 and will nominally use a four air gun array in two modes: firing together and ramp-up through the four air guns. The actual number of air guns and their capacities will be determined from the results of Experiment #1 with a single air gun work and the propagation model generated in 2010, as well as feedback from JIP experts. Tow paths will be the same as in Experiment #1.

General procedures for the east coast experiments.
In addition to visual observers on Emu Mt (which include a scan-sampling team and two or three focal follow teams), a small team of visual observers will operate from an elevated land-station approximately 10 km northwards. *Cyclops* software will be used for all visual sampling to ensure that data collected is in a consistent format. Observations on Emu Mt will include one or two focal follows (focal group) and scan-sampling (sampling all groups) with theodolite(s) and binoculars.

An array of five hydrophone buoys will be moored offshore NE of Emu Mt and will be used for recording the underwater acoustic environment (including seismic signals and whale vocalizations) and for tracking vocalizing whales (Figure 3). The acoustic tracks will be incorporated into the *Cyclops* software, displaying visual and acoustic tracks in almost real time. Two 5-6 m vessels will be used for finding whales, tagging, biopsy collection or behavioural observations during follows. A larger vessel (19 – 24 m) will be used for deployment of the air gun array.

Each BRS (exposure, control and non-exposure) will run as follows:

- Phase I – Focal group selection and tagging
  - Whale groups to the north of the main study area will be identified by land-based observers stationed approximately 10 km north of the main land-based observation platform, or by one of two small boats searching the area. Once one or two suitable groups have been identified, they are designated “focal groups”.
  - Females with calves, with and without additional adult “escorts”, will be the primary focus. Other groups of interest include single adults and pairs of adults either of which may include singing whales.
  - The tag boats will move in on the focal groups and attempt tagging with DTAGs

    - or similar or satellite tags for up to 45 mins.
    - If tagging is unsuccessful and another potential focal group has been identified in the area then tagging may be attempted on the new group.
- Phase II – Before BRS observations
    - The focal groups are handed over to the main focal observer teams on Emu Mt as they move down the coast for tracking and recording of all behaviours observed. Each of the two focal groups will be assigned to separate focal follow teams with their own theodolite. A third theodolite team will scan sample (tracking and behavioural observations) all groups in the area regardless of whether or not they are focal groups as well as all vessels. Observers with binoculars will assist in keeping track of all groups in the area.
    - Land-based visual observations of undisturbed whales must occur for at least 1 h after the end of any tagging attempt, with the aim of obtaining about 1 h of observations after the whales have returned to normal after tagging.
    - Depending on the range and composition of the focal groups, the tag boats may also focal follow each focal group at a distance of at least 500 m. This will aid particularly in obtaining measurements of the distance between mothers and calves. It will also be useful in comparing the results with the experiments off the west coast where all observations will be boat based.
    - The air gun vessel will position itself just north of the hydrophone buoy array and approximately 1.5 km offshore. Air guns will be deployed without active firing.
- Phase III – During BRS
    - While the focal whales are still some distance north of the gun boat, and providing there are no whales within 500 m of the air guns, the boat will head east (across the migration direction) at 4-5 knots, firing air guns (exposure) or with air guns in place but not firing (control) for a period of 1 h. For the second two path, the procedure will be the same, except that the course will be south east (45° to the migration direction). If a whale appears within 500 m of the gun boat then the air guns will be shut down.
    - There will also be experiments of non-exposure where observations of all phases are made but without the presence of the air gun boat.
    - Tracking and behavioural observations continue as for phase II.
- Phase IV – After BRS
    - Tracking and behavioural observations continue as for phases II and III for at least 1 h.
    - The gun boat will continue to move at its original course and speed.
- Phase V – Tag retrieval and biopsy collection
    - The small boats will move in to collect biopsy sample from the whales for sexing. The focal whales will be followed by boat until the tags are detached and collected.
    - For the longer lasting tags, a second boat will be taken by road and launched at a suitable site to collect the tag. The radio signal will be monitored from headlands to check the position of the tagged whale.

The design of each experiment will be revised based on the results of the previous experiments. Procedures and protocols will be established in Experiment #1 and maintained for the following experiments. Potential variations in the above plan may include:

- Variation in pre and post-observation periods, depending on typical behavioural reactions to tagging and BRSs.

- The air gun boat's initial position may be changed (e.g. moved further offshore) depending on where focal whales are in the study area and the types of reactions seen.

B.3.7 Details of Western Australian experiments

The experiments off the west coast will generally follow the protocols and procedures developed in the earlier east coast experiments, to the extent possible given the different environmental conditions. The first experiment (#3, W12) is intended to be a replica of Experiment #2 on the east coast, so will follow the same BDA design. Experiment #4 (W13) will involve a full air gun array and this will require some changes to the procedures, as discussed below.

There are no suitable land observation points on the west coast similar to those in the east coast study area and the whales are further offshore. Thus it will not be possible to use theodolite tracking and all observations will be vessel based. In place of theodolite observations, visual localization will be done by a number of different techniques, all based on the same principles used with the theodolite: measuring the compass bearing of the whale and the angle to the horizon. These include graticule binoculars, inverted sextant and calibrated digital photography. Also acoustic tracking will be limited to systems that record rather than radio data to a base station. To test if this difference in observation technique affects the results, we will do sample trials of the same observations techniques off the east coast during the first two experiments and do a statistical comparison using these data with the results using the theodolite data.

The primary study area lies to the north of Exmouth between the Murion and Barrow Islands and between the 20 and 100 m depth contours, since most whales pass through this area. There are sufficient whales (including calves) out to a depth of 200 m for the experiments to be conducted in this area. A wide scale chart of the study region is shown on Figure 4 and includes the tracks of several seismic surveys for which the air gun signals have been measured by McCauley. A more detailed chart of the preferred study region is shown in Figure 5. The known main southbound migratory route for humpback whales through the study region is shown in yellow in Figures 4 and 5. At the north end of the study region southbound humpback whales pass around the top of the Monte Bello Islands (north of Barrow Island) and pass south traveling at around 3 knots or 5.5 km/h (based on satellite tagged whale speeds, Jenner and Gales pers. Comm.) centred approximately along the 50-90 m depth contour but spread over a wide band from around 20 m to the deep ocean (see Figure 2.33 in McCauley et al 2003 for cross slope humpback distributions in the southbound migration in the proposed main study region). Most southbound mother-calf pairs and attendant mature males, funnel down the yellow shaded area shown in Figures 4 and 5. North of Serrurier Island few whales venture inside of the 20 m contour.

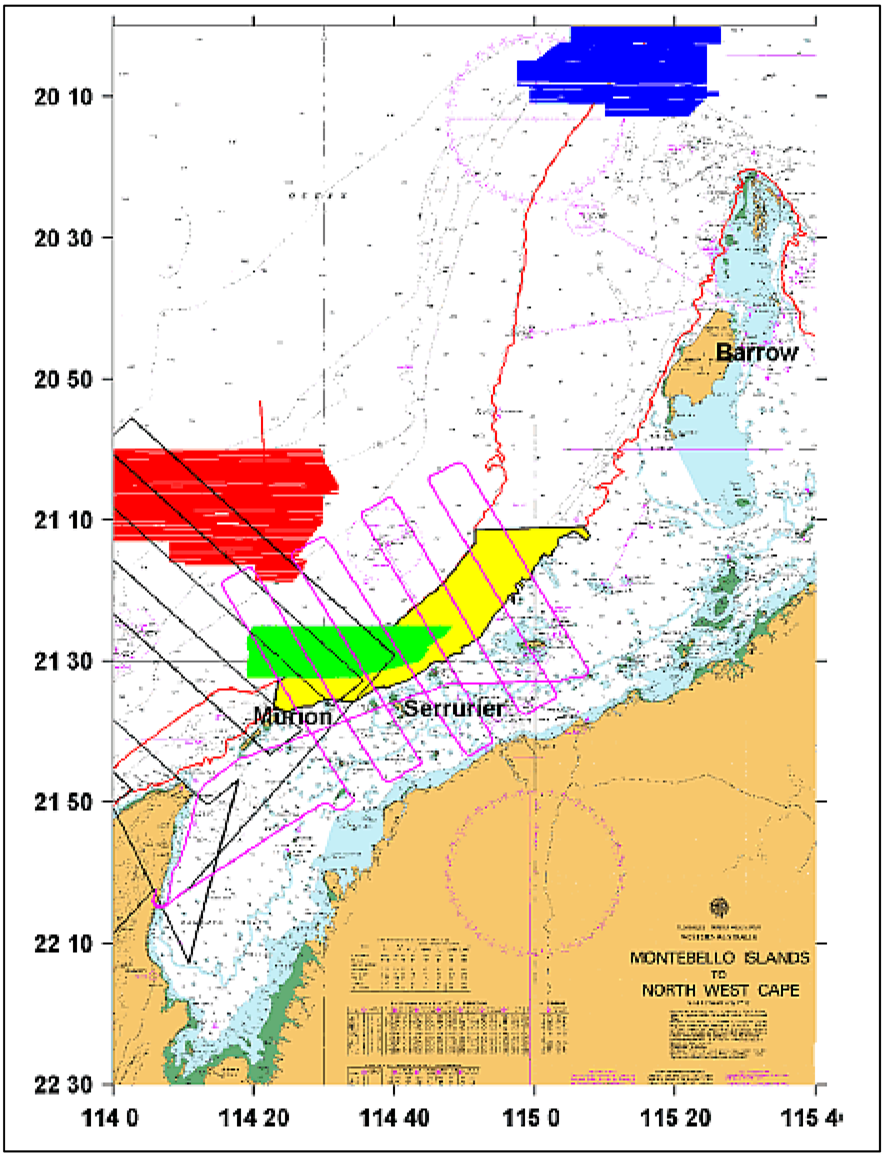


Figure 4: Location of general region in which Western Australian experiments will take place. The blue, red and green sections are seismic survey lines which have been measured (McCauley) while the red lines show the 20 and 100 m depth contours through which most southerly migrating humpbacks will pass. The yellow shaded area is the preferred location for the experiments; although there are sufficient whales in 200 m of water for the experiments to be moved out to there (this would involve greater transit time each day). The black lines represent aerial survey tracks run in the region most years since 2000, the magenta lines are a series of aerial survey tracks run in 1996 in conjunction with the green seismic survey. The image is based on Chart AUS 328 from the Australian Hydrographic Survey Office. Depths are in m.

Movements of whales through the area have been observed from aerial and vessel surveys (McCauley et al., 2003 and from 2000-2009: Jenner personal communication). These have shown that a high proportion (but not all) of mother-calf pairs pass between the Murion Islands and Serrurier Island to enter Exmouth Gulf where they switch behaviour to resting and milling. The noise from four large commercial seismic surveys have been measured in this region, with the survey lines of three shown in Fig. 4 and a fourth survey measured to the west near North West Cape. Thus the propagation of seismic signals in this area is reasonably well understood. There is also behavioural and distributional data on the movement of southerly traveling humpbacks moving past a commercial seismic array (2648 cui) in the study region (see McCauley et al 2003, plus several unpublished reports – McCauley and Jenner 2001, McCauley and Duncan 2001, McCauley, 2006).

The 24 m vessel *RV WhaleSong II* will act as the mother ship to the two offshore dinghies and the base for the whale observation data, with a whale observation platform 7 m high. The air gun vessel will also have an observation team and will be the primary platform for deployment of acoustic monitoring hardware (this can also be done by *RV WhaleSong II* which has a one tonne A-frame and winches). The smaller boats will select whales for tagging and focal follows and follow these whales through the study area. As for the east coast experiments, grids of moored sea noise loggers plus autonomous drifting systems and weather permitting, hydrophones hung off vessels, will be used to characterize the acoustic field throughout the study area. The measurements of the air gun array sound field will be compared to estimates from sound propagation modelling and knowledge of the seismic source, verified by measurements made in the field and a large data set made in the region historically (in excess of 100,000 shots recorded from multiple receivers set through the region). These systems will also be used to track vocalizing whales during post experiment analysis of the data.

All vessels will have VHF and satellite phone communications and be able to keep in contact at all times, with hourly radio checks. A safety radius from a mother ship will be set for the small vessels, nominally 10 n mi at this point, with all the small vessels having full offshore survival equipment and redundancy in communications.

CMST-DSTO sea noise loggers and a drifting housing with multiple vertically spaced hydrophones will be set in the area, with 3-4 loggers set in a triangle 0.2 – 2 km (0.1 - 1 n mi) NE of the air gun transect for tracking singing whales in the air gun area, and a line of loggers spaced along the study area out to 55 km (30 n mi) to record air gun signals at different distances. The tracking array will use a modified pinger, set to ping once per day at 7.5 kHz to synchronise each noise logger‘s independent clock. This technique has been proven by CMST and has been used several times. The moored noise loggers will remain in-situ, taking frequent samples for the full or half duration of the study. A nominal sampling frequency of 10 kHz and duration of 20 minutes of every 25 minutes, with one 200 s, 16 kHz sample per day will give a 40 day duration using the standard 58 GB HDD we use. We may use multiple sampling schedules for the tracking grid near to the air gun operations, with one schedule set to sample at much lower gain (total system gain of -10 or 0 dB) to avoid system saturation for very close air gun signals. This will halve the sampling period with the air gun vessel servicing the noise loggers.

Experiment #3 – Western Australia: components of ramp-up studies to compare with #1 & #2.

The first experiment (#3, W12) off the west coast will be 22 operational field days, including exposure, controls and bad weather days. On average, bad weather sufficient to limit the experimental work can be expected on less than 2 days out of 7 (2 has been used in the estimates). This experiment is intended to compare the responses of the two populations to noise exposure. It will be a replica of parts of the east coast experiments, using the same procedures and protocols except that all the focal follow observations and other visual observations will be done from vessels. Also acoustic tracking will be limited to systems that record rather than radio data to a base station. To test if this difference in observation technique affects the results, we will do sample trials of the same observations techniques off the east coast during the first two experiments and do a statistical comparison using these data with the results using the theodolite data. Focal follow groups will be selected about 10 km north of the proposed air gun track and followed through the area, conducting similar observations to those made during the east coast experiments, except that theodolite observations will be replaced by vessel based observations.

The treatments in this experiment will be two of the air gun combinations used in the east coast experiments on one tow path. A period of 22 days would provide 30 samples for the exposure and 15 for controls if we achieve two samples per exposure run and can obtain controls on the same day as exposure (by operating before the exposure). The choice of the actual air gun combinations and tow path direction will be based on the results of the Experiments #1 and #2 off the east coast.

RV WhaleSong II and the vessel used to tow the small array (components of ramp-up) in the first experiment off the west coast (#3, W12) will operate daily from an excellent anchorage near Serrurier Island, about 7 n mi from the study region. This tow vessel will probably be a 24 m modified Western Australian aluminium planning hull, lobster fishing vessel.

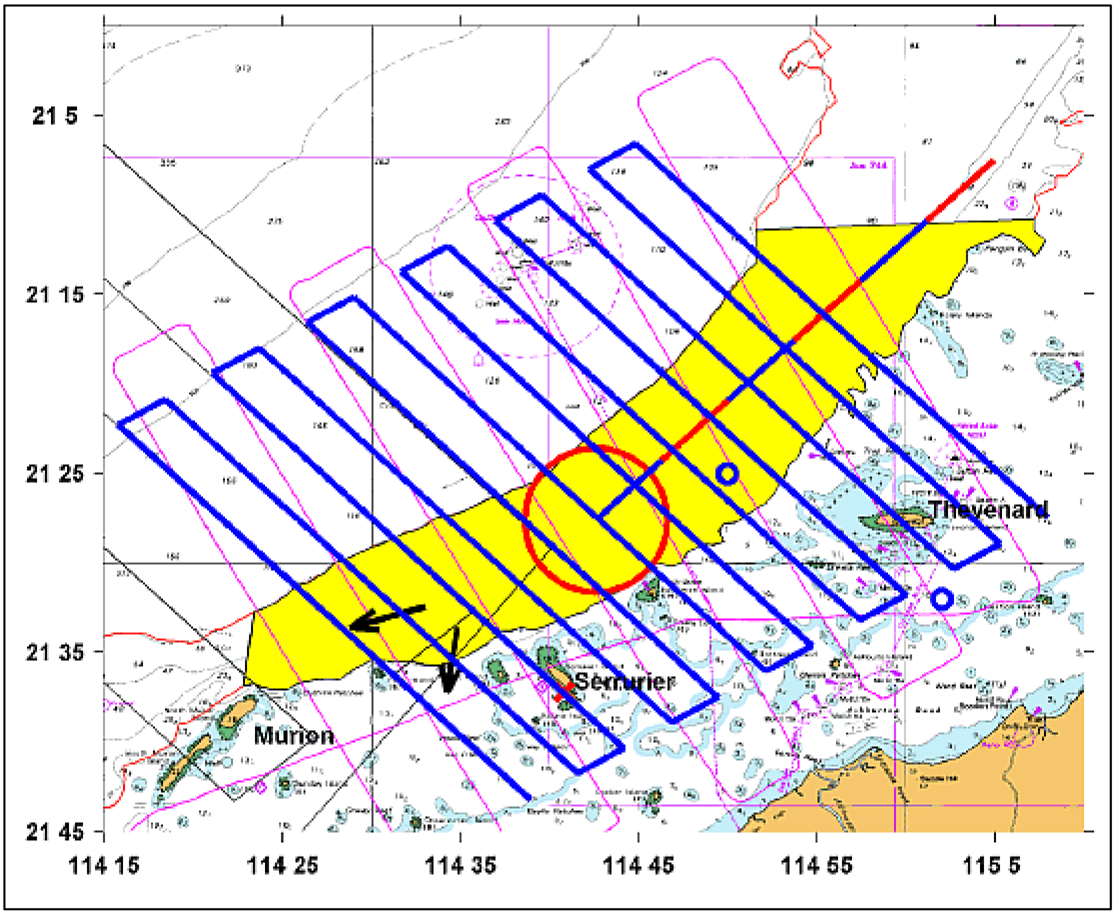


Figure 5: Detailed chart of the proposed Western Australian humpback study area. The red circle is the proposed site for all air gun operations (a 4 n mi or 7.4 km radius circle is shown), the yellow shaded area is bounded on the east by the 20 m depth contour and on the west by the 100 m contour and is the usual humpback migratory route. The air gun operations and observations could be moved further NW since there are sufficient whales out to about 200 m depth (the first contour NW of the yellow area, shown by a thin line, is the 200 m line). Red crosses show potential anchorages. The line extending to the NE from the centre of the circle of air gun operations is stepped in 5 n mi or 9.3 km sections to give an indication of scale. The heavy blue lines showed the proposed aerial survey transects to span the full scale of humpback whale movements. The black thin line (SW end) shows aerial survey tracks carried out over 2000-2009 by the Jenners and the magenta thin line aerial survey tracks carried out by McCauley et al (2003) during the southbound humpback migration. The heavy arrows show the usual way cow-calf pairs head into Exmouth Gulf or continue south (typically no co-calves). The small blue circles are locations of currently deployed sea noise loggers. Based on Chart AUS 328 from the Australian Hydrographic Survey Office with depths in meters.

Experiment #4 – Western Australia: exposure to full seismic air gun array

Experiments with humpback whales exposed to a full scale operational seismic array will take place over a 35 day field season in September, October 2013, though it could be interchanged with experiment #3 in September, October 2012, depending on availability of a suitable vessel.

The vessel and array have yet to be determined. One option being considered is to use the National Science Foundation vessel *RV Marcus Langseth* which has an air gun array with total capacity of up to 6600 cu in. An array configuration with the lower capacity typical of industry seismic surveys would need to be used for the experiment. Another option would be to contract a vessel with a suitable full scale seismic array from the region.

The experiment would be conducted in the region between the 20 and 100 m contours shown in yellow in Figure 5 or further NW out to the 200 m contour. Most whales pass through the yellow region and the 200 m line is about the limit of adequate numbers of whales including calves. Two 24 m vessels (one being *RV Whalesong II*) with at least two, and possibly three, offshore rated small support vessels would be used for focal follows, tagging, biopsy work and as observational platforms. Vessels will be based at Serrurier and to the north off Thevenard Island, as shown in Figure 4. Whale observational techniques will be similar to east coast and the previous west coast experiments, using visual observation and tracking from three platforms.

The design of this experiment will depend to some extent on the results of the Experiments #1 to #3 that precede it. The following discussion of the experimental design presents our current thoughts. Input from stakeholders and scientific experts would be welcome in refining this design. The procedures and protocols would follow those of the earlier experiments, with an important exception. Experiments #1 to #3 will use the well-established “before,” “during” and “after” experimental design with nominally 30 minutes for each, in order to compare reactions of whales to air guns with their behaviour before the air gun array was started and after it ceased. A commercial seismic survey, however, does not stop after 30 min, so a more realistic interpretation of the “after” period is that it is the period during which the whales return to normal behaviour as they move away from an array that continues to operate as is normal in a commercial survey. The exposure would commence with ramp-up typical of those use in a commercial survey.

The observations would focus on three regions: one within 2km of the array at start up to test the effects of ramp-up on nearby whales; one 2 - 10 km from of the array with the intention of providing the close range reactions to ramp-up and the full array; the other over a much larger distance (30-55 km) to follow the reactions of whales coming into exposure at low levels. DTAGs would cover the region within 10 km, while longer term tags (a few days or so) would be used to obtain information on whales over a much larger area.

The daily procedure would commence with the selection of suitable whales to tag and to focal follow. The air gun array would not commence operations until tags are in place, the whales have returned to normal behaviour and an adequate period of “before” observations have been obtained. The air gun array would then commence operation with typical ramp-up and continue with the full array for several hours. The actual duration of the period of operation will be determined based on what is learnt about whale reactions and the distances at which these occur in the earlier experiments. There are two opposing criteria that need to be met (a) the array needs to operate long enough for whales that have passed the array to have returned to normal behaviour (b) the array needs to cease operation before the whales that will arrive the next day are close enough to hear the array, i.e. so that the next day‘s whales are not pre-exposed to the air gun array. Some initial modelling suggests that the period for the operation of the array might be 7 – 10 h.

During this experiment, the air gun array would be towed along two tow paths and there would be controls in which the array would be towed along the same paths with air guns in place but not operating. The nominal tow paths are across the migration (NW-SE) and diagonally (E-W) but the final paths will be determined from the results of Experiments #1 to #3. The decision whether to commence operating the air guns or to run the control on any day will not be provided to the staff conducting the observations as a way of keeping them “blind” to the use of the treatment.

During all field days humpbacks will be tagged at around 30-55 km (15-30 n mi) NE of the air gun transect and focal follows made of whales approaching the air gun transect from these distance. The tagging vessels and the mother ship, *RV WhaleSong II,* will operate from Thevenard Island and end up at the air gun transect late each afternoon, then steam north back to Thevenard to anchor (pending weather, with Serrurier offering the safest anchorage). Given that many mother-calf pairs may rest during daytime, then focal follows towards the operating air gun may need to begin at 20-30 km (10-15 n mi) to the NE of the air gun transect. Typically the average whale travel speed through this area is around 3 knots (5.6 km/h), based on satellite tagged animals but this may decrease through late afternoon when many cow-calves often rest (e.g. see description in McCauley et al 2003 section 2.2.2 of resting mother-calf in the vicinity of an operating 2648 cu in array).

Aerial surveys with Experiment #4 during the full commercial array exposures.

During the full commercial seismic array experiments off the west coast (Experiment #4, W13), it is proposed to conduct a series of aerial surveys to study variations in the broad scale distribution of the humpback whale migration. The aim is to determine if the presence of a seismic air gun survey changes the spatial distribution of the whales migrating through the area. This would be achieved by obtaining an estimate of the distribution of the whales with respect to the air gun array, both when the array is operating and during the control runs when the air guns are towed but not being fired. Surveys would be conducted on days of air gun operation and days of control.

The design will follow line transect survey methodology and statistical techniques for estimating abundance and the density distribution of animals (Buckland *et al*. 2004). The aerial transects will be on headings of 134° and 314° similar to the transects of the seismic array and approximately at right angles to the migration paths, as shown in Figures 4 and 5. The transects will be 55 km (30 n mi) long and separated by 5 km, providing a 2.5 km observations strip either side of the aircraft‘s track. The proposed 12 legs of each survey of 30 n mi length, extend either side of the migration strip by at least the width of the strip, reaching into shallow water at the SE side and to around 200 m depth on the NW side. As presented the flight path is around 4:25 hours from the Exmouth light aircraft airfield, at 120 knots, which is a comfortable period for the aircraft and observer crew from a fatigue point of view.

Currently ten flights are budgeted for, but this may increase pending the aircraft type. Aerial surveys will aim to be run early in the morning, weather permitting, to enable the aircraft whale sightings to be relayed to the vessels to aid in finding whales. A fixed wing aircraft fitted with bubble windows to maximize visibility at close ranges to the aircraft will be used. Double blind observers will be used during the surveys, meaning that observer perception biases can be modelled and corrected for by having double observers on each side of the plane which are acoustically and visually separated, hence provide independent sightings. The surveys will be conducted commencing at the southernmost transect and ending on the northern most transect (against the migration), so that any chances of double counting the same animals are minimized.

Previous and current aerial surveys (by the Jenners) will provide a substantial amount of data for comparison. The proposed surveys overlap with part of these, have the same headings but half the separation to provide finer resolution.

Statistical analyses

Pod density will be estimated using a spatial generalized additive model (GAM) or Generalized Linear model (GLM). The response variable of the model will be the number of pod sightings per "segment" of transect, where the segment length is generally double the effective strip half width (Buckland *et al*. 2004). An offset (or correction) is included in the model to account for differences in estimated probabilities of detection within each segment given the variability in conditions such as sea state, glare, and observer. This will be done through multiple covariate distance sampling (Marques and Buckland, 2003), and will be done using either R or Distance 6 (Thomas *et al.* 2006).

Model fitting and selection will be done in the mgcv or glm package in R (Wood 2008). GCV scores will be used to compare models. Variance for the spatial model will be estimated using bootstrap techniques or other less biased approaches (Wood, 2006). Potential spatial covariates/predictors will include latitude, longitude, and water depth. Temporal variables will include Julian day and air gun levels across the transect (before, during, and after).

B.3.8 Sample size for BRS

The east coast experiments will involve 10 weeks of active field effort over the 2010 and 2011 seasons. During these experiments we hope to conduct approximately 40 exposures (air guns firing) to whales, at least 15 controls (air guns towed but not firing) for each tow path and 15 non-exposures (no vessel or air guns), all to whales with no recent history of exposure to air gun sounds. Data will be collected on individual behaviours at three resolutions (in descending order of numbers of individuals and ascending order of detail): (1) scan sampled, (2) focal followed, (3) tagged. For the 40 exposure experiments to naïve whales we plan to focal follow around 80 whale groups (i.e. usually two groups in each experiment for most experiments) with at least 30 of these tagged. Teams for Woods Hole Oceanographic Institution successfully tagged 30 humpbacks at this site over four weeks (compared with our 10 weeks) in previous experiments, but these were random whales, not necessarily ones correctly positioned in time or space as BRS focal whales.

This will allow for approximately five tagged whales for each treatment and control for the east coast experiments and a similar number for Experiment #3 off the west coast that emulates some of the east coast work.(single air gun east tow path, single air gun north tow path, four air gun array and ramp-up). At the focal follow level, this will give us a minimum of 15 samples per treatment and control. Tag deployment and focal follows will concentrate on mother-calf and mother-calf-escort groups to provide a sufficient sample size to determine differences in reactions due to social context. We also expect to record at least one singer per exposure experiment.

For the first set of experiments off the west coast (Experiment #3, W12), the procedure will follow that of the earlier east coast experiments. Two treatments will be used, the choice being made from the results of the east coast experiments based on which produced the strongest reactions. This is designed to test the model developed from the results of Experiments # 1 and #2 (E10 and E11) off the east coast as a way of comparing the reactions of the whales of the east and west coast populations. Focal follows will be conducted by observers in two or three offshore capable small vessels, together with observations from the mother vessel, giving potentially two whale groups that can be focal followed in each experiment. Exposure, control and non-exposure will follow the design of experiments E10 and E11. DTAGs or similar will be used as for the east coast experiments, as well as longer term tags Two experiments (a control and a treatment) will be conducted each day, is suitable weather. At this stage, 21 days have been allocated for the field work, which, allowing for expected periods of adverse weather, should be enough to obtain an adequate sample, but this can be reassessed using the results of the east coast work.

The second set of experiments off the west coast (Experiment #4, W13), using a commercial seismic array be conducted over a period of 35 days in the field. This is expected to provide about 25 days with weather suitable for the small boat observations. For each of these, there would be at least two focal follows. As well as DTAGs or similar, it is intended to longer term recording tags and satellite tags. The detailed design of this experiment will be developed using the results of the first three experiments, and power analysis studies using these results. Additional observations of whales moving in the vicinity of the observation vessel will be made from the air gun vessel.

The results of each experiment will be used to fine tune the design of subsequent experiments.

B.3.9 Measurement of whale behaviour

The project team includes Australia‘s most experienced humpback whale researchers who collectively have decades of experience collecting behavioural data. Behaviours can be broken into six broad categories: (1) horizontal movement; (2) vertical movement; (3) surface-active behaviours; (4) vocal behaviours; (5) group cohesion; and (6) group splitting and joining. Horizontal movement data will be used to determine properties such as heading, velocity and their rates of change. These will be measured by focal theodolite follows (east coast experiments), small boat focal-follows (east and west coast experiments), GPS location from tagged whales (east and west coast experiments), fast-lock GPS satellite tags over days to weeks (east and west coast experiments). Vertical movement includes dive periodicity and interval available from visual observations in addition to fine-scale dive profiles and fluking rates from DTAGs or equivalent and longer term tags capable of measuring dive profiles. In lieu of theodolites, the vessel based operations will determine whale positions (relative to the vessel‘s position which will also logged) using graticule binoculars, inverted sextant and calibrated digital camera with compass. “Cyclops” will be used in as a way of standardizing visual and acoustic data collection, annotation, storage and display between platforms and sites.

Surface-active behaviours will be defined using a single ethogram. This will include surfacing rates, time at surface and a series of common humpback behaviours. Humpback whales exhibit many behaviours, such as blowing, no blow rising, logging, head rising, spy hopping, lunging, breaching, pectoral flipper slapping, fluke slapping, inverted fluke slapping, peduncle slapping, sailing, etc. While we aim to collect detailed observations, we also realize that too many categories of behaviour can lead to confusion and indecision on the part of observers, and best-practice is a compromise between detail and ease of use.

Underwater behaviour will be measured by DTAGs or equivalent (several hours) and longer term tags (a few days). Underwater acoustic behaviour can also be used as a measure of underwater behaviour and behavioural change (e.g. Miller et al. 2000) and will be collected remotely using moored systems (for all vocalizing whales) as well using DATGs on a small number of individuals. Humpback whales are very vocal and we expect to detect changes in both their songs and other social sounds with respect different noise exposures. High energy surface-active behaviours are also routinely heard underwater and may indicate responses to the air gun signals.

Group cohesion or the spacing of individuals in a group (for example, between mother-calf pairs) will be recorded. Distances between groups (inter-group spacing) will be estimated using range and bearing measurements using graticule binoculars, inverted sextant and calibrated digital camera with compass.
Social context (i.e. group composition) will be noted throughout the experiment as well as any

changes in these. Humpback social interactions are fluid and whales or groups of whales are constantly joining together to form larger groups and splitting apart into smaller groups. Standard echograms and data collection protocols will be developed for each platform so that data are compatible across platforms and study sites.

B.3.10 Power analysis

Data from a "tones" playback experiment carried out on the east coast humpback whale population (2004 and 2008) was used as a basis to predict the response of humpback groups to the air gun stimulus. The levels received by whales during the tones playback were quite low (generally less than 120 dB re 1 μPa rms, for 1.5 s) tens of decibels less than the expected received levels from the proposed air guns proposed (whether mean square or sound exposure level). We therefore assume the response to the air gun sounds in the proposed experiments will be more pronounced than the response to tones, so this analysis should be a conservative estimate of the sample size required.

Three response variables were chosen (based on their significance as response measurements) to carry out a power analysis; mean course travelled, mean number of surfacings and mean deep dive time during the 20 minutes exposure ("during") period. The significance level is set at 0.05 (the alpha or likelihood of falsely rejecting the null hypothesis that there is no effect) with a probability of detection of 0.8 (which corresponds to a beta, or probability of falsely not rejecting the null hypothesis, of 0.2). Mean course and mean down time per experimental period are normally distributed. The mean number of surfacings per experimental period (Poisson distributed) was normalized using a square root transformation. The sample size calculations are based on an independent group's t-test analysis, comparing control (non-exposed) groups to groups exposed to tones in the 20 minute "during" period of the experiment. Means and standard deviations were calculated and compared between the "during" experimental period. The sample size required for detecting a change in response was calculated for each effect size and is illustrated in Figure 7.

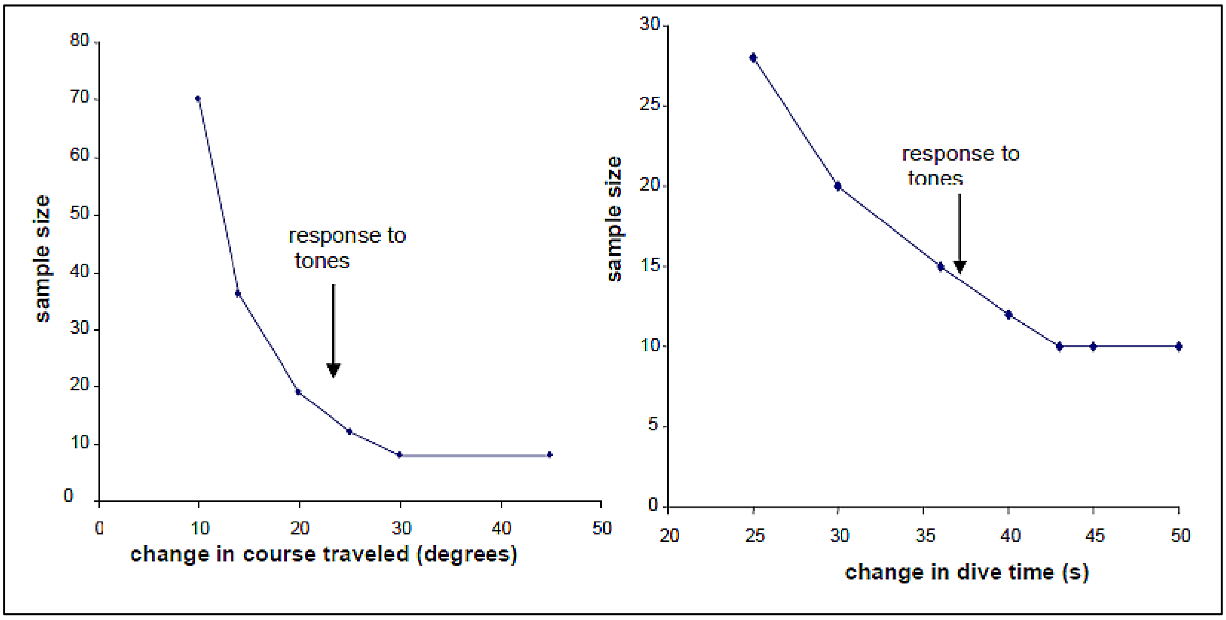


Figure 7: Sample size curve for detecting a change in course (degrees) and change in deep dive time (s).

The graphs show the response to the "tones" stimulus (x axis) and the sample size required to detect the response with a power value of 0.8 (y axis). The magnitude of the responses in our experiments (indicated by the arrows) show that a statistically significant response to tones is not likely to be detected unless more than 10 samples are taken (15 sample for the change in course and 12 for the change in dive time). If we assume that the response to the much higher level air gun stimulus is more pronounced, then we predict that a **minimum** sample size of 10 focal follows per treatment should be a sufficient sample size with which to detect a significant response to an air gun stimulus. A similar result was found for change in (normalized) number of surfacings. To be conservative, we will base the experimental design on a minimum of 15 samples per treatment.

The experiments have been designed to allow us to focally follow 15 replicates per treatment; however, all of them may not be tagged. To overcome this problem, associations between tagged and non-tagged animals will be tested (we will be testing how long it takes for whales to return to normal behaviour after tagging, to ensure that observations are taken after that time period).. If this prediction holds true, behavioural correlations will be developed in tagged animals that are also focally followed and these correlations will be used to impute missing values from non-tagged (but focally followed) animals. However, this will over-estimate the precision of the data therefore the analysis must be treated with caution. This will only be carried out if the results of the power analysis for tagged animals (which will be performed after the 2010 study) shows that we require a larger sample size than is logistically possible for the study.

The power analysis will be repeated using the results of the first experiment in 2010 (E10) and the results of McCauley et al. (2003) for 16 BRS using a 20 cu in air gun carried out in Exmouth Gulf in 1996 & 1997 on resting humpbacks (as opposed to southerly migrating ones). This will allow us to revise the design of the second experiment (E11) to optimize its effectiveness. Power analysis will also be conducted after the 2012 (W12) experiment #3 to further fine tune the design.

B.3.11 Data analysis

Behavioural response

For most of the focal follow data, general(ised) linear mixed models (GLMM; incorporating fixed effects, covariates and random effects) will be generated using the statistical software package "*R*" (R Foundation for Statistical Computing). This analysis will follow closely that used for previous playback experiments on the east coast. Behavioural response variables (e.g. course travelled, speed, dive profile, surface behaviours, vocalization parameters) from the focal follow dataset will be averaged over each experimental period. Responses will be modelled using GLMMs with appropriate choice of link and distribution functions (depending on the distribution of the response variable). *Fixed effects* (those which are determined by the experimenter), include exposure (exposed/non-exposed), treatment (single air gun, multiple air guns, ramp-up, full array and controls), tow-path, experimental period (pre, during and post-exposure), and social context (group composition and nearest neighbour). *Covariates* (other variables that might affect the results) including array proximity, array movement, received level, and background noise, will be incorporated as additive and/or interactive effects. *Random effects* are those where the levels of the effects are assumed to be randomly selected from an infinite population of possible effects, in this case, the selection of test groups from a large population. The variance from this "random effect" is also included in the model. The use of a mixed model also allows the incorporation of the variance associated with using more than one observation per experimental unit, i.e. where multiple measurements are taken on a single subject (a repeated measures design). The sequence of behaviour of the focal followed groups falls into this category. Fixed effects will be introduced and removed (depending on their significance in influencing the response) and generated models will be compared using likelihood ratio tests and AIC scores to assess which model (i.e. combination of fixed factors) best explain the data. AIC (Akaike Information Criterion) scores show which model best fits the data. Multivariate analysis methods may also be used which will incorporate a number of response variables into the model and therefore determine the multivariate response.

Tag data will be examined using Trackplot (Ware et al. 2006), which is a visualization tool that replicates the continuous movement and orientation of the whale as a ribbon. The ribbon includes depth, pitch, roll and depth which can be linked to time and geographic position. From the time and positional data, course travelled and speed can also be calculated. The geographic data from the tag will be calibrated against the theodolite data or other information about the whales' position. The tag output dataset is a time-series plot of time (x-axis) versus response variable (course, orientation, depth, pitch, roll, etc.). The x-axis can be standardized to "time from start of experimental period" to allow the comparison between tagged animals and/or between the three (BDA) experimental periods and exposure treatment. The tag data provides fine scale detailed individual responses as a continuous time series. For example, fluking rates and pitch movements can be used as a proxy for locomotion effort (Miller et al. 2009), vocal effort can be measured by vocal rates and source levels and the 3D movement can be used to determine dive profile and horizontal movements. Various regression models (e.g. a generalized least-squares model for longitudinal data or time-series analysis) will be employed to determine effects such as the time-scale of the response of tagged individuals to the air gun stimulus. A least squares method can be used to fit a generalized linear model. Due to the fact that repeated measures are taken on an individual, the data will be tested for autocorrelation between data-points. This autocorrelation function (if applicable) will be included in the model to account for the correlated errors within the dataset. Other covariates such as "array proximity" and "received level" as well as the fixed effects can then be included as before.

From the results of experiment #1 (E10, east coast) we will develop a response model to a single-gun array. This initial model will form the basic model. Response variables will be tested against three initial independent factors; the "state" of the air gun (on, off, absent), experimental period ("before", "during" and "after") and tow path direction (north, east). Other independent factors and covariates will be added in, for example, received level, proximity, direction of travel relative to the source vessel and social context to determine which factors and covariates contribute significantly to the behavioural and vocal response of whales. Experiment #2 (E11, east coast) will continue building and developing this model by comparing the responses generated in the basic model to responses generated from exposure to a larger air gun source. Depending on the final experimental design, ramp-up through the first few stages may also be added in as a fixed effect.

The west coast experimental design for #3 will emulate that used on the east coast, though not all treatments will be used. The west coast data will then feed in to the model developed in the east coast, adding "population" as an independent factor. To ensure comparability between the two populations, the model output using the east coast data only will be tested using the data from the first west coast experiment (#3) for the exposure that is matched at both sites (response to two air gun treatments on one tow path). In addition, tag data from both study sites will be analysed in the same way and analysis of the tag data will provide a comparable link between the two study sites. This approach provides an efficient way of linking the two sites and provides a robust model which has been tested on two different populations. The final model, rather than a simplified dose-response model, will be a more complex behavioural response model highlighting the significant vocal, movement and fine scale behavioural responses to small air gun arrays and (due to the robust sample size) factors and covariates that contribute to this response; for example proximity to the source, received level and other social and environmental effects.

The final experiment on the west coast (# 4, W13) will test the behavioural response of humpback whales to a full seismic array and the associated ramp-up. Data from this experiment will feed in the previously developed behavioural response model to determine if (and how) the response differs with a full seismic array and the relative significance of factors and covariates contributing to the response between the different array types. We will also develop a separate model for the full array experiment and compare predictions with those of the original model. The information gained in the east coast experiments will also be used to predict responses to the full array and full ramp-up and tested with the results of the experiment #4. The east coast experiments will provide more detailed and higher resolution data than is possible with the full array experiments, allowing us to better understand the effects on the whales and to apply that to the full array results. The combined results will allow us to determine how responses vary with factors and covariates that differ between the experiments and the relative contribution of the variables.

Other previously analysed datasets (such as the response of humpbacks to playback of conspecific vocalizations, frequency-modulated tones and the normal behaviour of whales obtained from earlier experiments i.e., not including those used as controls in the proposed experiments) will be incorporated into the full analysis. This type of experimental design allows the comparison of humpback whale behaviour before, during and after exposure to an air gun stimulus, between exposed and non-exposed groups targeted in these experiments, between groups exposed to other stimuli such as conspecific sounds and “tones” and between groups observed in the study areas with no experimental manipulation. Using this dataset, the response of humpbacks to an air gun stimulus can be placed into the context of their response to other stimuli and as well as in the context of their “normal” behaviour. Therefore some interpretation can be made about the biological significance of the response to air guns.

Acoustic data

Acoustic data will be analysed for absolute received levels by reference to known calibration signals (white noise) using **SpectraPlus** or **SpectraPro** (Sound Technology Inc.) and custom MATLAB programs.

The received levels of transient signals such as air gun sounds and whale sounds will be measured as sound exposure level *SEL*, which is defined in terms of the integrated sound pressure squared over the duration of the transient:

$$SEL = 10\log_{10}\left(\int_T p^2 dt - \int_T p_n^2 dt\right)$$

Where p is the instantaneous acoustic pressure including the signal of interest and the background noise, p_n is the instantaneous background noise pressure and T is a time interval encompassing the signal transient of interest. The integral;

$$\int_T p_n^2 dt$$

cannot be measured over the period T when the signal is present (because it includes the signal as well as the background noise), so is usually estimated over another period of time equal to T during which only the background noise is present. This assumes that the background noise is statistically stationary and ergodic, so that the result will be similar for any period T. In practice, this is a reasonable assumption if the noise integral is calculated near the time of the signal, i.e. within minutes.

Measurements of the mean square sound pressure level (also known as root mean squared pressure level) will also be made where appropriate. Mean square pressure level is the time average of the *SEL*:

$$SEL = 10\log_{10}\left(\frac{1}{T}\int_T p^2 dt - \frac{1}{T}\int_T p_n^2 dt\right)$$

In a plane wave, mean square pressure is proportional to the sound intensity averaged over the time *T*, while *SEL* is proportional to the sound energy flow through unit area over the duration of integration.

B.3.12 Air gun array design

The design of the arrays to be used in the experiments will follow those typical used by industry in commercial surveys. The details are yet to be determined and will be based on advice from JIP and the Minerals Management Service. In Experiment #1 in 2010, only the first air gun used in ramp-up will be used, and all that needs to be decided is the capacity of this air gun. We have a 20 cu in air gun (owned by Curtin University) and this size is used as the first air gun in ramp-up in some arrays. For experiment #2 in 2011 we need specifications of air guns and the array configuration that might typically be used in the first few stages of ramp-up. The results of Experiment #1 will feed into this decision in terms of the types of reactions observed. Experiment #3 in 2012 will emulate part of Experiment #2. Finally, the design of the full array in Experiment #4 in 2013. We have the capability at Curtin University to model the sound fields produced by the chosen array designs in the horizontal direction as appropriate to exposure of whales, based on what we measure for the propagation at the site.

B.3.13 Project constraints and risk mitigation

The proposed project is large and complex. It probably requires the building of an air gun array as well as the preparation of hydrophone buoys and bottom mounted acoustic loggers. The operation of multiple platforms simultaneously at sea is needed during the limited migratory periods available and the weather needs to be conducive to the safe and effective operation of the experiments. A large number of personnel with various levels of training and technical skills are required. Whales need to be successfully tagged with both DTAGs or equivalent and implantable satellite tags and the tags need to work correctly.

The risk of operational failure is reduced markedly, or will be managed, by the following: Our extensive experience in running field work on humpback whales at both field sites (four previous seasons of similar work at the east coast site with many years before that at nearby sites, and many years of work with humpback whales off the west coast including two seasons conducting seismic BRSs).

1) Our extensive experience in the use of most of the techniques, methodologies and items of equipment that will be used including single air guns.
2) Budgeting for adequate technical assistance so that the additional components required for this study can be provided and maintained in the field.
3) Bringing in adequate expertise with backups for tagging, boat driving, etc. and providing an adequate training period for volunteer observers (east coast)
4) Spreading the field efforts over four years (including the pilot study) so that incremental improvements can be made to study design, to best manage the use of equipment and personnel at two field sites, to avoid fatigue of personnel, and to mitigate to some extent against possible extended periods of bad weather that might occur in a particular year.

5) The use of properly trained personnel for running the air guns.
6) The preparation and implementation of strict procedures and protocols covering areas such as safety, operation of equipment, the collection of data and tagging approaches.
7) The employment of a Project Coordinator to shoulder many of the administrative tasks associated with the project, to keep individual researchers to agreed time-lines and to develop many of the necessary protocols and procedures.
8) Inclusion of a statistician with expertise in the design and analysis of ecological experiments.
9) Not having to rely entirely on tag data at the east coast site.

There are several constraints within which we must work.

1) It is not possible to use a full commercial air gun array at the east coast site. It is, however, a very suitable site to do controlled experiments on ramp-up procedures and provides a higher degree of control than could be achieved in areas where a commercial array can be used.
2) There are a number of constraints on the provision of the commercial air gun array in 2012 off the west coast. At this stage we do not have a full commercial-sized array available. The JIP may be able to request such a survey from one of the OGP members
    a) Operating a commercial array during the main period of migration when we would want to conduct our experiments may require special permitting.
    b) A commercial array operated as part of a commercial survey would not be under our experimental control and so we may not be able to build in control studies with vessel and array operating but no guns firing.
    c) A commercial array dedicated to the experiment may be difficult to arrange, given availability and cost. The *RV Marcus Langseth* may be the best option.
3) The use of small boats at sea and tagging is possible only in relatively calm weather for both safety and logistical reasons. We have allowed for this in our calculations of field time necessary to collect adequate sample sizes. Both DTAGs and satellite tags can be difficult to place on whales and the west coast experiments in particular will rely heavily on our success in this regard. Tagging of humpback whales, however, is easier than on many other whales and more than 30 DTAGs were successfully deployed on humpbacks off the east coast site over a four week period previously. Also, unlike many other species, it is possible to conduct focal follows (boat and land-based) of humpback whales without tags so that we are not completely reliant on tagging success. While completely benign land-based observations are possible at the east coast site, we are constrained to use boat-based focal observations at the west coast site. While this will reduce data collection rate, it is thus because the whales are further offshore, and this, in turn, makes it possible to use full commercial air gun arrays. The permits are provided by the Australian, Queensland and Western Australian governments (state waters extend to 3 nautical miles from shore) and the animal ethics approvals granted by our institutions. Providing the source level of the air gun array at the east Australian site is low and we agree to air gun shut downs in line with the Australian guidelines or if triggered by perceived detrimental behaviours (e.g. calf separating from its mother) that we will write into our procedures and protocols, we do not envisage any particular issues with obtaining these permits and approvals.

Further analysis of risks, management and mitigation is given in Table B.6.

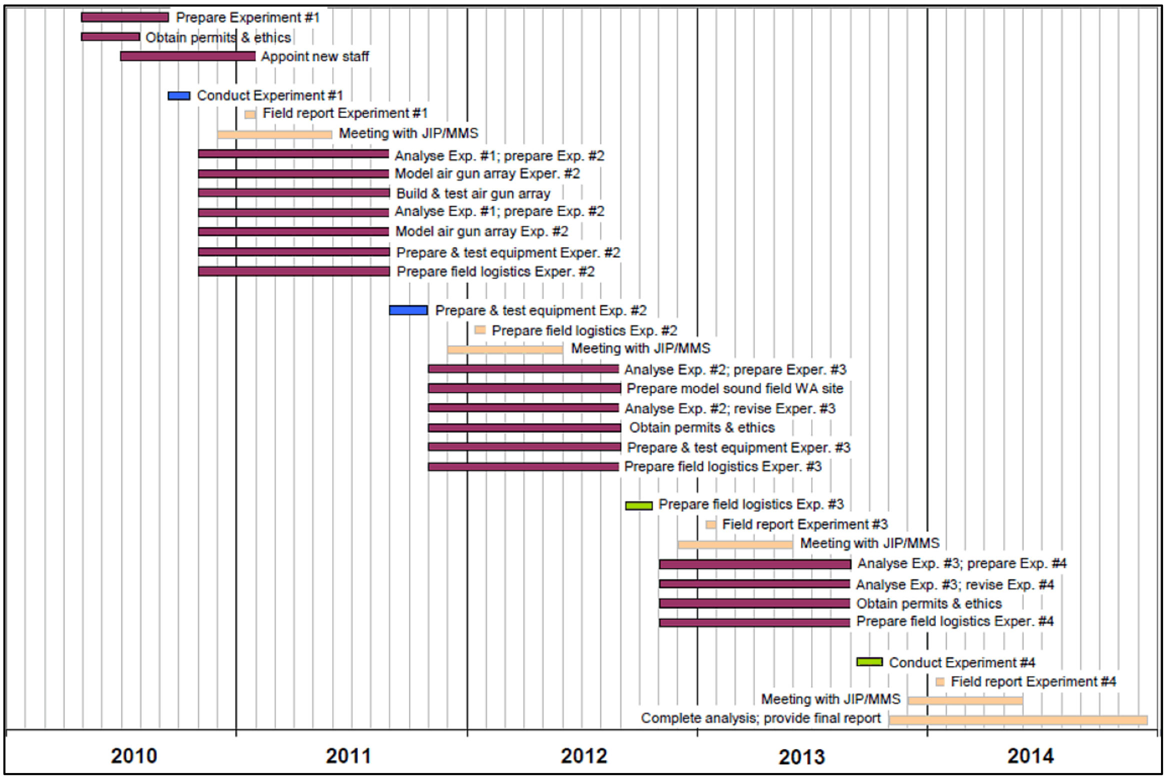
RISK	LIKELIHOOD	CONSEQUENCE	MANGEMENT
Typical periods of bad weather	High	Operations cease on these days	Allowed for in experimental plan. Bad weather days used as rest days and for maintenance and data assessment.
Unseasonable bad weather	Low	Operations cease on these days	Multi-year experiments limit the effect of this.
Equipment failures	Medium	Loss of some data	Most equipment has been extensively tried and tested through use and new equipment will be extensively tested. Our procedures of maintenance, spares, redundancy or identified replacements, ensures that only a small amount of data lost.
Commercial seismic survey not available for Expt. 5 (WA12)	High	Loss of typical commercial seismic array as BRS source	(1) Can interchange year of Expt. 5 with Expt. 4 (WA11) (2) NSF vessel *RV Marcus Langseth* may be available (3) We have designed a scaled array that produces a similar sound field horizontally to a full commercial array
Failure to attach sufficient DTAGs or equivalent	Low - previous DTAG attachments to humpback whales at the east coast site had high success rate	Loss of dive data Loss of acoustic data on received level at whale	Have allowed for a proportion of failures to attach; focal follows still provide good data on dive patterns, speed, course, behaviour, etc. Have allowed for a proportion of failures and autonomous acoustic systems (acoustic buoys, loggers) and knowledge of propagation loss will allow the sound fields at the whales to be determined
Loss of DTAGs or equivalent	Low to medium – none lost in previous work	Loss of capability to collect tag data	Will carry sufficient spares
Failure to attach satellite tags	Low – this is usually easier than DTAGs as can be fired into whales rather than placed.	Loss of medium term (days to weeks) behavioural reaction data	Successful deployment of all satellite tags is not critical to project success: have allowed for a proportion of failures. Use of highly experienced satellite tagging personnel.

Table B.6. Risk management and mitigation analysis for project operation.

PERIOD	EVENT
May – Aug 2010	Prepare equipment for Experiment #1. Prepare field logistics. Develop detailed measurement protocols.
By Aug 2010	Obtain permits for experiments (Animal ethics, State and Federal approvals)
July 2010 - Feb 2011	Appoint new staff
Sep-Oct 2010	Conduct experiment #1 (E10) in EA.
Jan 2011	Field report on Experiment #1 with preliminary analysis, new power analysis with revision of design for Experiment # 2.
Dec 2010 - June 2011	Meeting with JIP/MMS on Experiment #1and proposal for Experiment #2.
Nov 2010 to Aug 2011	1) Process data and analyse results of Experiment #1. Revise experimental design for Experiment #2 based on results. 2) Model air gun array sound fields for Experiment#2, EA 3) Build and test air gun array for Experiment #2 and characterize acoustic field 4) Standardize all field measurement protocols for Experiment#2, data sharing and data backup procedures 5) Obtain permits (Animal ethics, State and Federal approvals) 6) Prepare and test equipment for Experiment #2, EA 7) Prepare field logistics for Experiment #2, EA
Sep-Oct 2011	Experiment #2 (E11): second experiment in EA
Jan 2012	Field report on Experiment #2 with preliminary analysis, new power analysis with revision of design for Experiment # 3.
Dec 2011 - June 2012	Meeting with JIP/MMS on Experiment #2 and proposal for Experiment #3.
Nov 2012 to Aug 2012	1) Process data and analyse results of Experiment #2. Revise experimental design for Experiment #3 based on results. 2) Prepare model of sound field at WA site based on known experimental array character and existing air gun propagation measurements within the site. 3) Standardize all field measurement protocols for Experiment#3, 4) Obtain permits (Animal ethics, State and Federal approvals) 5) Prepare and test equipment for Experiment #3, WA 6) Prepare field logistics for experiment #3, WA
Sep-Oct 2012	Experiment #3m, (W12): first experiment in WA
Jan 2013	Field report on Experiment #3 with preliminary analysis, new power analysis with revision of design for Experiment # 4.
Dec 2012 - June 2013	Meeting with JIP/MMS on Experiment #3 and proposal for Experiment #4.
Nov 2012 to Aug 2013	1) Process data and analyse results of Experiment #3. Revise experimental design for Experiment #4 based on results. 3) Standardize all field measurement protocols for Experiment #4, data sharing and data backup procedures. 4) Obtain permits (Animal ethics, State and Federal approvals) 6) Prepare field logistics for experiment #4, WA
Sep - Oct 2013	Experiment #4 (W13), WA
Jan 2014	Field report on Experiment #4 with preliminary analysis
Dec 2013 - June 2014	Meeting with JIP/MMS on results of Experiment #4.
Nov 2013 – Dec 2014	Complete analysis of experiments and provide final report.

Table B.7: The project work program. Abbreviations are: EA = eastern Australia site; WA = Western Australia site.

B.4 Work plan including time table and milestones



Bar chart showing time table of activities and milestones. For meetings, the period during which the meeting is expected to occur is shown rather than the actual duration of the meeting (which would be much less).

B.5 Program organizational structure

The project will be led by the Chief Scientist (Cato) with a Steering Committee consisting of the PIs and the JIP staff as nominated by the JIP. He will be the scientific contact with the JIP. The Steering Committee will be responsible for setting science priorities within the project, overseeing the experimental design and operation, coordinating the project, and overseeing the analysis and reporting of data. The Committee will also be responsible for ensuring safety standards are industry best practice. The steering committee will meet at least twice per year, once in conjunction with the annual experiment series and once about mid-way between experiment series. There will be a meeting of all investigators at least once per year in conjunction with the annual experiment series.

A Project Coordinator will be employed full time for three years (through University of Sydney) and will work under the direction of the Chief Scientist. The project coordinator will be responsible for (1) administrative interactions with the JIP, (2) ensuring good lines of communication are maintained within the project and between the project participants and the JIP; (3) tracking finances, maintaining program accountability, reporting on the project finances to the JIP; (4) tracking deadlines; (5) assisting separate institutions to meet commitments, objectives and deadlines; (6) ensuring compliance with safety procedures and reporting and documenting correctly. The project coordinator will be expected to participate in field trials and to regularly visit the east and west Australian science groups.

The project coordinator will attend Steering Committee meetings.

The **principal investigator** roles and experience are as follows:

- PI Cato, is an authority on underwater acoustics and has been working on whales and bioacoustics for about 30 years. He was a PI of the previous humpback whale experiments (HARC) on the east coast.

- PI Noad, who was also a PI of the HARC experiments on the east coast will be officer in charge of the east Australian experiments, including preparation, management of resources, and OH&S. He has worked on whale behaviour and acoustics for 15 years and has extensive experience running projects at the east coast field site including previous BRSs as part of HARC.

- PI McCauley will be officer in charge of the west Australian experiments, including preparation, management of resources and OH&S. He will also be officer in charge of air gun operations. He has worked with underwater acoustics and whales for 22 years, and has extensive experience with seismic exploration technologies including the use of air gun arrays, starting in 1992, and BRS with air guns and humpback whales.

- PI Gales will be officer in charge of tagging. He is the Leader of the Australian Marine Mammal Centre, has been involved in marine mammal research for more than 20 years and is one of the world‘s most experienced taggers of large whales.

- PI Dunlop will be responsible for detailed experimental design and behavioural analysis. She has helped run three large previous experiments at the east coast site, is an expert of humpback whale social sounds and behaviour and has been responsible for much of the past data analysis as well as the power analysis for this proposal.

The **associate investigator** experience and roles are as follows:

- Dr Chandra Salgado-Kent will be contributing to the experimental design and statistical analysis. She has several years' experience in whale bioacoustics.

- Dr Jason Gedamke is an expert on whale acoustics and will be involved satellite tag work.

- Dr Simon Bloemberg (UQ) and Dr Ross Darnell from the CSIRO Mathematical and Information Sciences group, are experts in statistics specializing in statistical modelling for marine ecology experiments and will provide expert statistical advice on experimental design and modelling.

- Mr David Paton and Mr Curt Jenner will manage vessel operations and participate in the experimental work. They are probably the two most experienced boat operators around humpback whales in Australia, with extensive experience at both study sites including the deployment of satellite and DTAGs, in interpreting whale behaviour and with the logistics of conducting experiments on whales at sea.

- Dr Erik Kniest is the developer of *Cyclops* and will ensure effective operation of *Cyclops* and provide modification developments as required. He has extensive experience in surveying and tracking whales.

- Mr John Noad is a computer expert and former manager of large computing facilities. He will manage the computing facilities including the wireless and further development. He has participated in the previous humpback whale experiments on the east coast.

Principal Investigators	
Douglas H. Cato	0.3 FTE
Nicholas J. Gales	0.1 FTE
Robert D. McCauley	0.6 FTE
Dr Michael J.Noad	0.4 FTE
Rebecca A. Dunlop	0.5 FTE
Co-investigators	
Chandra P. Salgado Kent	1 FTE
Jason Gedamke	0.1 FTE
Ross Darnell/ Simon Bloemberg	0.08 FTE
K. Curt S. Jenner	field season
Hendrik Kniest	field season
John Noad	field season
David Paton	field season

Table B.8. Proposed proportion of investigator's time per year on the project. FTE: full time equivalent.

B.6 Availability of unique facilities

The institutions involved in this project represent a large proportion of the long standing Australian whale research groups (with the exception of blue whale workers from Victoria) and underwater acoustic research groups.

Unique facilities include the following:

- CMST maintains the technical capability of designing, building, maintaining and deploying sea noise recording equipment and the air gun array, plus has a powerful signal processing capability, a unique depth of theoretical knowledge of ocean and shelf acoustic phenomena, tremendous field experience including humpback whale air gun BRSs, a strong capability in preparing software code and a facility ideal for preparing the air gun array (Fremantle research base). West Australian experiments will rely on an ocean going research vessel operated by the Centre for Whale Research (AI Jenner). The vessel is equipped with CTD profiler, ADCP current meter, sea surface temperature logging, chlorophyll-a measurement and single beam sonar. The vessel also has heavy lifting capability.
- The east coast study site at Peregian Beach offers a unique combination of a very close inshore migratory path, an elevated land observation station that does not just into the migratory path (and so does not affect behaviour), and good logistical support with accommodation and nearby boat harbours. Previous work here in 2002, 2003, 2004 and 2008 provides a wealth of background data.
- UQ and DSTO jointly developed the hydrophone buoys and mooring systems used for the static array at the east coast site. These required several years' development but have been highly successful for recording acoustic signals and noise as well as tracking whales.
- The use of software packages of *Ishmael* and *Cyclops* and the use of a local computer network to make visual and acoustic tracking of whales available across the entire study

site is also a facility unique to the east coast site.

Details of three major unique systems that will be used throughout the experiments are as follows.

Cyclops

Cyclops is a software package developed by co-investigator Dr Eric Kniest (University of Newcastle). *Cyclops* provides a computer based multilayered map display of whale and vessel positions throughout the day, derived from theodolite and acoustic tracking and annotated with observed behaviours. Operation is effectively real time and it can be run on computers on the various operational platforms used in experiments with continual updating by wireless link. *Cyclops* will be used on all the proposed experiments to record and display whale movements and behaviour and vessel movements. It will be used extensively in the later detailed analysis. Figure 2 shows an example of the display, for a day during the Humpback Whale Acoustic Research Collaboration (HARC) experiments at the east coast site. The boxed comments in white have been added.

The first version of Cyclops was developed in the 1990s for visually tracking migrating humpback whales using a theodolite. Since then, Dr Kniest has worked with the HARC team to modify the original software extensively for the complex behavioural studies and tracking required. For theodolite tracking, a laptop computer with *Cyclops* is connected to the theodolite and at the press of a button, the theodolite vertical and horizontal angle data are fed to the computer and Cyclops calculates and plots the position. The station height and position are entered into *Cyclops* at the beginning of the season. *Cyclops* automatically keeps track of tide height and also computes atmospheric refraction using calibration shots at the horizon which are performed several times per day. Once the whale‘s position has been captured, the computer operator can alter various fields concerning the whale‘s behaviour and the composition and movement of the group in which that whale is travelling. Observations can also be entered with an approximate position instead of a theodolite fix so that all behaviours of all groups can be captured regardless of whether or not the theodolite operator manages to get a fix.

During HARC, *Cyclops* was also modified to read files produced by *Ishmael* software (Mellinger, 2001) and incorporate as another layer in the display. *Ishmael* determines acoustically the locations of sound sources such as vocalizing whales, surface-active behaviour and vessels by hyperbolic fixing using multiple hydrophones. *Cyclops* was modified to work as a network via wireless network designed by co-investigator Mr John Noad, so that the acoustic singer fixes from the base could be transmitted to the computer with the theodolite, and visual fixes from the hill could also be transmitted to the base station where the acoustic data were recorded. This allowed all positional and movement information to be displayed simultaneously at both stations so that interactions between singing and non-singing whales could be watched in real-time. The research vessels were directed to these interactions or other whales of interest over the radio.

Cyclops has been developed for the kind of experiments proposed and can be further developed as needs arise. It is planned to operate *Cyclops* over one of the commercially available 3G phone/data networks in the area (Telstra or Optus). On the east coast, this will enable us to run *Cyclops* on laptops in the boats which has two big advantages: (1) the boats will be able to see the positions of whales in real time and so will be more easily and efficiently be able to find these animals (e.g. candidates for focal groups), and (2) *Cyclops* on the boats will keep track of the boats‘ movements through an attached GPS on board each vessel, and the boats‘ positions will then be available in real-time to all computers on the network. This latter feature will not only increase the efficiency of the operation but also provide obvious safety benefits.

For our off-shore work on the west coast, the distance offshore may limit the extent that networking benefits of *Cyclops* can be used, however, *Cyclops* files from each platform can be merged at the end of each day to provide a single file for the day containing all whale movement and behavioural data as well as boat positional data in the same format as the east coast data. Most of the acoustic tracking data at the west coast site will also be analysed later on recovery of the recording systems, so will be incorporated into *Cyclops* at a later stage.

Acoustic Loggers.

The CMST-DSTO noise loggers are unique and extremely flexible long term autonomous acoustic recordings systems. A sea noise logger comprises an external hydrophone (usually Hi Tech HTI 90-U or Massa TR1025C) connected through an Impulse IEEE three pin bulkhead connector to logging electronics designed and maintained at Curtin. The loggers provide: impedance matching for the hydrophone; low-noise amplification in two stages, one programmable over 0-20 dB, for the hydrophone signal; signal conditioning with anti-aliasing filters and a low frequency roll off to flatten the naturally high levels of low frequency sea noise and thus reduce the input signals dynamic range while retaining the calibration; 16 bit A-D conversion; two input channels each with potentially multiple sampling schedules; storage capacity of up one or more 2.5‖ hard disks; and a fully programmable sampling regime set up using a serial link and PC / laptop communications package (using any standard text communication software).

The loggers are designed to be low-noise and low-power, with 42 D sized alkaline batteries capable of filling approximately 60 GBytes of hard disk space (actual logging capability is determined by the sampling schedule chosen). To reduce power consumption the loggers stream data to files on a flash card (power-cheap) then when the flash card is nearly full, run up the hard disk (power hungry) and write samples to disk. Thus they cannot run continuously, requiring a finite time to copy files from flash to hard disk although long files can be saved (so far up to an hour per file) or multiple loggers with offset set start times used to capture a full time series. The loggers have been used to measure air gun signals from 45 m off a 3255 cu in array or directly underneath 3040 and 2390 cu in arrays without signal clipping. We modify the pre-amplifier gain to suit expected signal levels. If we wish to collect high intensity signals plus ambient noise the loggers are configured with two almost simultaneous samples (one byte offset) with one schedule set to collect say air gun signals and the other ambient noise.

Physically the noise loggers fit into a 100 mm ID tube and are 300 mm (old models) or 150 mm (new models) in length. The loggers are calibrated using white noise of known intensity input with the hydrophone used, in series. We have found that having the hydrophone in series is critical to correct calibrations for frequencies below 20 Hz. For frequencies below 1 Hz only high capacitance hydrophones can be used, we have one GIC32 hydrophone (capacitance 0.45 µF) which will measure down to near DC. The loggers are typically calibrated from 1 Hz to the anti-aliasing cut-off frequency.

The loggers can be set to sample from 1 to 24 kHz. It is expected that a sample rate of 10 kHz per channel to be used in air gun trials with an anti-aliasing frequency of 4.8 kHz. The loggers use quartz crystal clocks with an accuracy found to be within ± 1 s / day. The logger clocks are set to UTC time via a GPS link before deployment and the drift read after deployment, again to GPS, UTC time. The logger clocks jump when going in or out of water (sharp temperature change), thus for tracking purposes we use a modified ORE, CART, acoustic release set to ping at 7.5 kHz once per day, every 20 s for 35 minutes. In this configuration one logger sample per day is set to capture a selection of acoustic release pings and from the geometry and known sound speed, the relative drifts of all loggers to a designated master logger can be calculated to around 1 ms accuracy. The CMST has made long term deployments (greater than one month) of these loggers around Australia in excess of 140 times now. CMST currently has about 20 sea noise loggers in the water around Australia.

Moored hydrophone and transmitter buoy systems.

These were developed by DSTO and the University of Queensland and were the main systems used to provide the acoustic data for tracking and recording acoustic sources such as vocalizing humpback whales whale surface behaviour and vessels during HARC experiments at the east coast site from 2003 to 2008.   Each system is moored for months at a time and sends acoustic data continuously to shore by radio link. There are short periods when a system is down for maintenance and battery changes, although each has a panel of solar cells that minimizes the down time. Each system includes a hydrophone (usually High Tech MIN96) with preamplifier, a secondary amplifier (with selectable gain), a VHF FM transmitter (from an ambient noise sonobuoy, modified for the purpose), batteries and solar panel.

Mechanically, the buoy is designed to keep the transmitter antenna vertical and to follow the rise and fall of the waves, as is needed for adequate transmission of the vertically polarized radio signal.   It consists of a vertical pressure rated PVC pipe, about 3 m in length, passing through fiberglass buoy with elliptical cross section and filled with close-celled foam. Most of the weight of the buoy (batteries) is near the bottom of the pipe. The point of attachment of the mooring line to the pipe is designed to work with the weight distribution of the buoy and the spar shape to keep the system vertical. The elliptical float allows the buoy to move vertically with the waves. The system can be deployed and recovered using a small boat. Batteries can be replaced at sea with recharged ones and minor maintenance done without removing the buoy from the moorings.

Since the buoy can rotate around the main mooring anchor, the hydrophone is moored from a separate anchor to limit its movement. This is important for acoustic tracking, since the accuracy depends on the accuracy in determining the hydrophone positions.

At least three and usually five complete acoustic buoy systems (including moorings) are usually deployed for tracking. For HARC there were arranged in a T-shape with three buoys roughly parallel to, and 1.5km from, the beach and the fourth and fifth buoys placed on the perpendicular bisector of the line through the first three buoys. Adjacent buoys were separated by about 750 m. A similar format is proposed for the east coast experiments.

Radio transmissions are received at a base station just behind the beach on a large, vertically orientated Yagi antenna connected to multichannel VHF attached to a four channel, low noise, VHF receiver. The outputs are connected to multichannel National Instruments data acquisition cards in the data recording computers. Recording is controlled by *Ishmael* software (Mellinger, 2001) which records continuously or can be programmed to sample at regular intervals. Currently we are developing a communication link to allow switching to be carried out remotely. For example, the gain of the amplifier in the buoy could be changed by radio link as required, depending on received levels. The acoustic data is fully calibrated allowing absolute sound levels in the water to be calculated. Calibrations are conducted on individual units and the complete systems at the DSTO hydrophone calibration facility at Woronora Dam in Sydney.

The positions of the individual hydrophones are surveyed in using a laser theodolite from the beach and mirrors on poles above each hydrophone. The accuracy of acoustic tracking depends directly on the accuracy of this positioning.

These systems have been used extensively and have proved to be robust and capable of long term deployment. They will be used at the east coast site as with HARC where they can cover the 10 km radius from their centre. It may be less feasible to use them moored at the west coast site where activities will move over a wider range. They could be deployed as drifting systems, with a drogue attached to the mooring point and with a GPS beacon to continually update their positions. This would allow real time tracking. We have used the positioning system effectively on other systems.

B.7 Deliverables

Project deliverables primarily comprise a series of progress reports, a final report, a series of draft journal papers, visual material for the JIP public relations and the PIs presenting the project results at international forums. These deliverables are listed in Table B.9.

Date	#	Deliverable
Apr 2010	1	Contract signing.
Aug 2010	2	Report summarizing activities for period, to include: progress with permits and animal ethics approvals; details of staffing; preparedness for Experiment #1; period highlights and problem summaries.
Jan 2011	3	Report of Experiment #1 (Peregian 2010 east coast field trials) with field summaries, meta data table summarizing all data collected, incident reporting and results of preliminary analysis including propagation modelling; field planning document prepared for 2011 east coast trials including air gun array size and design; highlights and problem summaries.
Jul 2011	4	Report summarizing activities for period, to include: progress with permits and animal ethics approvals; details of the air gun array preparation; analysis of Experiment #1 field trials; field planning document prepared for 2011 east coast field trials; details of staffing; summary of expenditure; period highlights and problem summaries.
Jan 2012	5	Report of Experiment #2 (east coast 2011) with field summaries, meta data table summarizing all data collected, incident reporting and results of preliminary analysis; field planning document prepared for 2012 west coast trials; period highlights and problem summaries.
Jul 2012	6	Report summarizing activities for period, to include: progress with permits and animal ethics approvals for west coast trials; analysis of Experiment #2 field trials; field planning document prepared for 2012 west coast field trials; period highlights and problem summaries.
Jan 2013	7	Report of Experiment #3 (2012 west coast) field trials with field summaries, meta data table summarizing data collected, results of preliminary analysis and incident reporting; field planning document prepared for 2013 west coast trials; draft report of analysed results to date of Experiments #1 and 2 (east coast field trials); period highlights and problem summaries.
Jul 2013	8	Report summarizing activities for period, to include: progress with permits and animal ethics approvals for west coast trials; analysis of Experiment #3 field trials; field planning document prepared for Experiment #4 (2013 west coast field trials with full commercial array); period highlights and problem summaries.
Jan 2014	9	Final report of east coast trials presented; field summary of Experiment #4 (2013 west coast trial) with summary data meta data table summarizing data collected, results of preliminary analysis and any incident or safety reporting; highlights and problem summaries.
Dec 2014	10	Final project report submitted summarizing all project activities, results and how experiments met project objectives, aims and original hypothesis. Journal manuscripts in advanced preparation or completed on response of humpback whales to seismic air gun ramp-up, response to commercial seismic arrays, the relationship of these responses to normal behaviour, and response to other stimuli, and the effectiveness of ramp-up as a mitigation measure in seismic surveying. Presentations at conferences on results to date as opportunities arise. Whale tracking and behavioural data supplied in standardised ASCII text formats. All air gun signal measures and waveforms supplied in standard Matlab and ASCII text formats. Period highlights and problem summaries. PI's present results at venue / time nominated by the JIP – seminar style presentations at workshop / conference etc.

Table B.9: Program deliverables

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- Ware, C., Arsenault, R., Plumlee, M. and Wiley, D. (2006). ―Visualizing the Underwater Behaviour of Humpback Whales.‖ Computer Graphics and Applications, vol.26, no.4, Jul.-Aug. 2006, pp.1418.
- Würsig, B., Gailey, G., McDonald, T. L., Nielson, R., Ortega-Ortiz, J., Wainwright, P. W., et al. (2002). Western gray whale occurrence patterns and behaviour: Shore-based observations off Sakhalin Island, August–September 2001. Report by Texas A&M University, Galveston, TX, for Exxon Neftegas Limited, Yuzhno-Sakhalinsk, Russia (70pp.). Available from Exxon NeftegasLimited, c/o ExxonMobil Development Company, 17001 Northchase Drive#466, Houston, TX77060, Attention: Daniel Egging.
- Würsig, B., Gailey, G., Sychenko, O., &Petersen, H. (2003). Western gray whale occurrence patterns and behaviour: Shore-based observations off Sakhalin Island, August – September 2002. Report by Texas A&M University, Galveston, TX, for Sakhalin Energy Investment Company Limited and Exxon Neftegas Limited, Yuzhno-Sakhalinsk, Russia (48pp.).
- Würsig, B., Weller, D. W., Burdin, A. M., Blokhin, S. A., Reeve, S. H., Bradford, A. L., et al. (1999). Gray whales summering off Sakhalin Island, Far East Russia: July – October 1997. A joint U.S.- Russian scientific investigation. Report by Texas A&M University Galveston, TX, and Kamchatka Institute of Ecologyan Nature Management, Russian Academy of Sciences Petropavlovsk, Russia, for Sakhalin Energy Investment Company Limited and Exxon Neftegaz Limited, Yuzhno Sakhalinsk, Russia (101pp.).

- Wood, S.N. (2008). ―Fast stable direct fitting and smoothness selection for generalized additive models‖. JRSS Series B. 70, 495-518.

- Yazvenko, S. B., McDonald, T. L., Blokhin, S. A., Johnson, S. R., Melton, H. R., Newcomer, M. W., Nielson, R., & Wainwright, P. W. (2007). Feeding of western gray whales during a seismic survey near Sakhalin Island, Russia. Environmental Monitoring Assessment, 134, 93–106.

C. Biographies of Investigators

Principal Investigators

DR DOUGLAS H. CATO

Affiliations. (a) Defence Science and Technology Organisation (DSTO) Australia. PO Box 44, Pyrmont, NSW 2009, 13 Garden St. Eveleigh NSW AUSTRALIA. Ph.: +61-2-9381 0172, Fax: +61-2- 9381, doug.cato@dsto.defence.gov.au
(b)Adjunct Professor and Director, University of Sydney Institute of Marine Science (USIMS), University of Sydney, NSW 2006, AUSTRALIA. Ph.: + 61-2-9036 9245, Fax: +61-2-9351 0184, dcato@usyd.edu.au
Qualifications: B.Sc. (Geophysics), M.Sc. (marine bioacoustics), Ph.D. (underwater acoustics) (University of Sydney).

Membership of learned societies, boards etc.: Fellow of the Acoustical Society of America; member of Australian Acoustical Society, Australian Marine Sciences Association, Society for Marine Mammalogy. Board of International Commission on Acoustics (04-07). Member, Ocean Policy Science Advisory Group (advises Australian Government).

Main research interests: Marine acoustics, particularly the ambient noise of the ocean, both physical and biological sources, marine bioacoustics and animal communication and impact of anthropogenic noise on marine animals.

Recent distinctions: Chief of Defence Force and Secretary of the Department of Defence, Environment and Heritage Award, 2008. Two papers in the 50 short listed for the best papers in 100 years of Australian defence science.

Research experience and main achievements:
Forty years of experience in marine acoustics particularly ambient noise, propagation and source localization including Chief Scientists of many experiments at sea. Thirty years' experience in marine bioacoustics, including acoustic signals, effects of noise and population dynamics. Research leadership in marine science.
Determined the characteristics of ambient sea noise from physical, biological and shipping sources for the Australian Indo-Pacific region from extensive experiments and modelling.
Developed the first comprehensive theory of sound generation by motion of fluid interfaces such as the sea surface which has been verified by measurement.
Established the characteristics of the humpback whale song for Australian stocks, geographical and temporal variation and differences from northern hemisphere songs.
Architect and a PI of the Humpback Whale Acoustic Research Collaboration.

Refereed Publications since 2005.

- Wright, K.J., Higgs, D.M., **Cato, D.H**. and Leis, J.M. (2010). ―Auditory sensitivity in settlement-stage larvae of coral reef fishes.‖ Coral Reefs, 29, 235-243.
- **Cato, D.H.** (2008) ―Ambient noise and its significance to aquatic life.‖ Bioacoustics, 17, 21-23.
- **Cato, D.H.** (2008) ―Ocean ambient noise: its measurement and its significance to marine animals.‖ Proc. Institute of Acoustics, 30 (5) (9pp).
- Jennifer L. Miksis-Olds, J.L., Buck, J.R., Noad, M.J., **Cato, D.H**. and Stokes, M.D. (2008) Information theory analysis of Australian humpback whale song. *J. Acoust.Soc. Am.* 124, 2385-2393.
- Dunlop. R.A., **Cato, D.H.** & Noad, M.J. (2008) Non-song acoustic communication in migrating humpback whales (*Megaptera novaeangliae*). *Mar. Mamm. Sci.* 21, 613-629.
- Dunlop, R,A., Noad, M.J., **Cato, D.H**. and Stokes, D. (2007) ―The social vocalization repertoire of east Australian migrating humpback whales (Megaptera novaeangliae)" *J. Acoust. Soc. Am.* 122, 2893-2905.
- Dahl, P.H., Miller, J.H., **Cato, D.H.** and Andrew, R.K. (2007) ―Underwater ambient noise,‖ *Acoustics Today*, **3**, 23 – 33.
- Noad, M.J. and **Cato, D.H.** (2007) Swimming speeds of singing and non-singing humpback whales during migration. *Marine Mammal Science*, 23, 481 – 495.
- **Cato, D.H.**, McCauley, R.D., Rogers, T. and Noad, M.J. (2006) ―Passive acoustics for monitoring marine animals - progress and challenges.‖ Proc. Acoustics 2006, 20-22 November 2006, Christchurch, New

Zealand, pp 453 – 460.

- Thode, A.M., Gerstoft, P., Burgess, W.C., Guerra, M., Stokes, M.D., Noad, M.J. and **Cato, D.H.** (2006) ―A portable matched-field processing system using passive acoustic time synchronization.‖ *IEEE Journal of Oceanic Engineering*, 31, 696 - 710.
- Lemon, M., Lynch, T.P., **Cato, D.H.**, and Harcourt, R.G. (2006) ―Response of travelling bottlenose dolphins (*Tursiops aduncus*) to experimental approaches by a powerboat in Jervis Bay, New South Wales, Australia.‖ *Biological Conservation*, 127, 363-372.
- **Cato, D.H.**, Noad, M.J. and McCauley, R.D., (2005) "Passive acoustics as a Key to the Study of Marine Animals", Chapter 13 of *Sounds in the Seas: from Ocean Acoustics to Acoustical Oceanography* edited by H. Medwin, Cambridge University Press, Cambridge.
- Rogers, T.L., **Cato, D.H.**, Southwell, C., Chambers, M. and Anderson, K. (2005). Preliminary investigations – appropriateness of acoustic and visual surveys for Antarctic pack ice seals. *GESTS International Transaction on Acoustic Science and Engineering.* 3(1): 128-134.

DR. NICHOLAS J GALES

Dr. Nicholas J Gales - Australian Centre for Applied Marine Mammal Science, Australian Antarctic Division, 203
Channel Highway, Kingston, Tasmania 7050, Australia, T +61 (0)3 62323437, F +61 (0)3 62323351, E nick.gales@aad.gov.au

a. Professional preparation

Bachelor of Veterinary Medicine and Surgery, Murdoch University, 1980
PhD, Murdoch University, Australian sea lion demography and reproductive physiology, 1995

b. Current appointment

Leader, Australian Centre of Applied Marine Mammal Science, Australian Antarctic Division.

c. Selected publications

- **Gales, N. J**., and H. R. Burton. 1987. Ultrasonic measurement of blubber thickness of the Southern Elephant Seal, *Mirounga leonina* (Linn.). **Australian Journal of Zoology** 35:207-217.
- **Gales, N. J**., P. D. Shaughnessy, and T. Dennis. 1994. Distribution, abundance and breeding cycle of the Australian sea lion, *Neophoca cinerea*. **Journal of Zoology (London)**234:353-370.
- **Gales, N. J**., Williamson, P., Higgins, L. V., Blackberry, M. A., and I. James. 1997. Evidence for a prolonged placental gestation in the Australian sea lion. **Journal of Reproduction and Fertility** 111:159-163.
- **Gales, N. J**., and R. H. Mattlin. 1997. Summer diving behaviour of lactating New Zealand sea lions *Phocarctos hookeri*. **Canadian Journal of Zoology** 75:1695-1706.
- Costa, D.P, and **Gales, N. J**.2003. Energetics of a benthic diver: seasonal foraging ecology of the Australian sea lion, *Neophoca cinera*. **Ecolological Monographs** 73(1):27-43.
- **Gales, N.J**., Brennan, A. and Baker, R. 2003. Ethics and marine mammal science. **Marine mammals and humans** (Eds: **Gales, N.J**., Hindell, M., Kirkwood, R.). CSIRO Publishing, Melbourne, Victoria. 321-330.
- **Gales, N**.J., Kasuya, T., Clapham, P. and Brownell, R.L. 2005. Japan‘s whaling plan under scruitiny: useful science or unregulated commercial whaling? **Nature** 435: 883-884.
- Reeves, R.R. and **Gales, N.J**. 2006. Realities in Baiji Conservation. **Conservation Biology** 20:626-628.
- **Gales, N.J**., Clapham, P., and Baker, C.S. 2007. A case for killing humpback whales? Nature Precedings http://hdl.nature.com/10101/npre.2007.13.13.1.
- **Gales, N.J.,** Hindell, M and Kirkwood, R. (Editors) 2003. Marine Mammals and Humans: Fisheries, Tourism and Management. CSIRO Press, Melbourne, Australia. 446pp.

d. Professional focus

For the past 28 years I have worked in applied aspects of marine mammal science with a strong focus on interactions between humans and marine mammals. My research has involved working extensively with large and small cetaceans, pinnipeds and dugongs and on aspects of the management of marine industries (in particular fisheries and oil and gas), hunting (dugongs and whales) and tourism. I have published over 90 peer-reviewed papers and now spend most of my career working at the interface between science, policy and management.

e. Other affiliations

Head of Delegation, Scientific Committee of the IWC, 2002-Present
Australasian Coordinator, IUCN Cetacean Specialist Group 1994-Present
Member of the IUCN Seal Specialist Group 1991-Present
Board Member, Society of Marine Mammalogy 2002-2006

Committee of Scientific Advisors for Society of Marine Mammalogy, 2000-Present
Board of Editors, Marine Mammal Science, 2005-Present
Review Editor, Endangered Species Research, 2005 – Present
Scientific Steering Committee, for Tagging of Pacific Pelagics, USA, 2003-Present.

ASSOCIATE PROFESSOR ROBERT D. MCCAULEY

Centre for Marine Science and Technology, Curtin University, GPO Box U 1987, Perth, 6845, Phone 08 9266 7460, fax 08 9266 4799, email r.mccauley@cmst.curtin.edu.au

Education: 1993 - 2001, JAMES COOK UNIVERSITY, TOWNSVILLE - Part time PhD completed, "*Biological Sea Noise in Northern Australia: Patterns of Fish Calling*"
1987 - 1993, JAMES COOK UNIVERSITY, TOWNSVILLE - Completed MSc. Qualifying, started MSc. which was upgraded to PhD. status, topic as above.
1984 - 1986, JAMES COOK UNIVERSITY, TOWNSVILLE - B.Sc. - Majors in Zoology, Marine Biology

Recent work experience: Mar 1996 - present, Centre for Marine Science and Technology, Curtin University, Western Australia - Full time researcher operating under own funding. Currently working on biological sea-noise sources in Australian waters, under Defence, Industry and consultant funding. Current projects include: blue, humpback and other great whale censusing techniques using passive acoustic methods; air gun signal data collection and analysis; impacts seismic surveys on fish; studies into fish bio-acoustics; obtaining long term Australian sea noise records. Major focus of research is biological & ambient sea noise sources in Australian waters, production and transmission of underwater noise and effects of man-made noise on marine animals.

Experience related proposal: McCauley has been working on seismic survey implications since 1992. He has numerous related publications several current seismic projects including investigating transmission of seismic signals and observations and pathological examination of fish exposed to seismic survey signals in the field. In 1996 and 1997 McCauley organised and ran 16 humpback whale BRS experiments in Exmouth Gulf, Western Australia while concurrently running a large field monitoring program around an offshore seismic vessel.

Related publications:

- McCauley, R.D. (1994). *Seismic surveys*. In Swan, J.M., Neff, J.M., Young P.C., (eds.), Environmental implications of offshore oil and gas development in Australia - the findings of an independent scientific review. pp. 19-122, Australian Petroleum Exploration Association, Sydney, 695 pp.
- McCauley, R.D., Jenner, M-N., Jenner, C., McCabe, K.A., Murdoch, J. (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
- Penrose, J.D., McCauley, R.D. (1998) Underwater character and horizontal propagation of air-gun signals. **APPEA Journal**, 1998, 708-714
- McCauley, R.D., Fewtrell, J., Duncan, A.J., Jenner, C., Jenner, M-N., Penrose, J., Prince, R.I.T., Adhitya, A., Murdoch, J., McCabe, K. (2000). Marine seismic surveys - A study of environmental implications. **APPEA Journal,** 692-705
- McCauley, R.D., Cato, D.H. (2000). Patterns of fish calling in a nearshore environment in the Great Barrier Reef. **Phil. Trans. R. Soc. Lond. B** 355:1289-1293
- McCauley, R.D., Fewtrell, J., Duncan, A.J, Adhitya, A. (2002). Behavioural, physiological and pathological response of fishes to air-gun noise. **Bioacoustics** 12(2/3):318-321
- Cato, D.H., McCauley, R.D. (2002) Australian research in ambient sea noise. **Acoustics Australia** 30:1-13
- McCauley, R.D., Fewtrell, J., Popper, A.N., (2003) High intensity anthropogenic sound damages fish ears. **J. Acoust. Soc. Am. 113(1):638-642**
- Jones, A.D., McCauley, R.D., Cato, D.H. (2003) Observations and explanations of low frequency clicks in blue whale calls. **Acoustics Australia**, 31(2): 45-50
- McCauley, R.D., Cato, D.H. (2003). Acoustics and marine mammals: Introduction, importance, threats and potential as a research tool. In (Gales, N., Hindell, M., Kirkwood, R. Eds) Marine Mammals, Fisheries, tourism and management issues. CSIRO Publishing, Melbourne, pp. 344-365
- McCauley, R.D., Fewtrell, J., Duncan, A.J., Jenner, C., Jenner, M-N., Penrose, J.D., Prince, R.I.T., Adhitya, A., Murdoch, J., McCabe, K. (2003). Marine seismic surveys: analysis and propagation of air-gun signals; and effects of exposure on humpback whales, sea turtles, fishes and squid. In (Anon) Environmental implications of offshore oil and gas development in Australia: further research. Australian Petroleum Production Exploration Association, Canberra, pp 364-521 available from http://www.cmst.curtin.edu.au/publicat/index.html#2000
- Popper, A.N., Fewtrell, J., Smith, M.E., McCauley, R.D. (2004) Anthropogenic sound: effects on the behaviour and physiology of fishes. **MTS**, 37(4) 41-53

- Cato, D.H., McCauley, R.D. Noad, M. (2005) Passive Acoustics as a Key to the Study of Marine Animals, in (Medwin, H. editor) Sounds in the Seas: Introduction to Acoustical Oceanography, Chapter 13, Cambridge University Press
- Gavrilov A.N, McCauley R.D. (2006) Feasibility of using seismic streamer arrays to track baleen whales. CMST Curtin University Report R2005-63, 18 pp., 16 Fig., available http://www.cmst.curtin.edu.au
- McCauley, R.D. Maggi, A. Rennie, S. (2007) Estimation of seismic survey signal transmission in and around Scott Reef Lagoon, Western Australia. Prepared for Woodside Energy, CMST Curtin University Report R2006-42, 51 pp. 38 Fig.
- McCauley, R.D., Salgado Kent C., Levings, A., Fischer, H., Lloyd, J., Beatty, A. (2007) Observations, catch and ear pathology of caged fish exposed to seismic survey passes. CMST Curtin University Report R2007-19, 62 pp. 45 Fig

DR MICHAEL J. NOAD

School of Veterinary Science, University of Queensland, Gatton Campus, QLD 4345, Australia**,** T +61 (0)7 3365 2088 F +61 (0)7 3365 1255 E mnoad@uq.edu.au

a. Professional preparation and current appointment

Bachelor of Veterinary Science (Hons), The University of Queensland, 1985-1990
PhD, University of Sydney, whale biology and acoustics, 1995-2002
Postdoctoral Research Fellow, The University of Queensland, 2002-2003
Lecturer, School of Veterinary Science, The University of Queensland, 2003-2008
Senior Lecturer, School of Veterinary Science, The University of Queensland, 2009.

b. Selected publications

- Miksis-Olds, J.L., Buck, J.R., **Noad**, M.J., Cato, D.H. and Stokes, M.D. 2008. Information theory analysis of Australian humpback whale song. Journal of the Acoustical Society of America 124(4):2385-2393.
- Dunlop. R.A., Cato, D.H. and **Noad**, M.J. 2008. Non-song acoustic communication in migrating humpback whales (Megaptera novaeangliae). Marine Mammal Science 24(3):613-629.
- **Noad**, M.J., Dunlop, R., Paton, D. and Cato, D.H. Absolute and relative abundance estimates of Australian east coast humpback whales (Megaptera novaeangliae). Journal of Cetacean Research and Management (accepted subject to minor changes, March 2008).
- Smith, J.N., Dunlop, R.A., Goldizen, A.W. & **Noad**, M.J. 2008. Songs of male humpback whales (*Megaptera novaeangliae*) are involved in intersexual interactions. Anim. Behav. 76:467-477.
- Dunlop, R.A., **Noad**, M.J., Cato, D.H. & Stokes, D. 2007. The social vocalization repertoire of east Australian migrating humpback whales. J. Acoustic. Soc. Am. 122(5):2893-2905.
- **Noad**, M.J. & Cato, D.H. 2007. Swimming speeds of singing and non-singing humpback whales during migration. Mar. Mamm. Sci. 23(3):481-495.
- Thode, A. M., Gerstoft, P., Burgess, W.C., Sabra, K., Guerra, M., Stokes, M.D., **Noad**, M. & Cato, D.H. 2006. A portable matched-field processing system using passive acoustic time synchronization. IEEE J. Ocean. Engin. 31(3): 696-710.
- Cato, D.H., **Noad**, M.J. & McCauley, R.D. 2005. Passive acoustics as a key to the study of marine animals. In: ―Sounds in the Sea: From Ocean Acoustics to Acoustic Oceanography‖ H. Medwin *et al.* Cambridge Uni. Press, Cam.
- Cato, D.H., McCauley, R.D. & **Noad**, M.J. 2004. Potential effects of noise from human activities on marine animals. Acoustics 2004, Australian Acoustic. Soc. Conf., Gold Coast, 3-5 Nov. Pp 369-74.
- **Noad**, M.J. & Cato, D.H. 2001a. A combined acoustic and visual survey of humpback whales off southeast Queensland. Memoirs of the Queensland Museum 47(2):507-523.
- **Noad**, M.J., Cato, D. H., Bryden, M.M. , Jenner, M-N. & Jenner, K.C.S. 2000. Cultural revolution in whale songs. Nature 408(6812):537.

c. Professional focus

My main research interests are the acoustic behaviour of humpback whales, the impacts of noise on cetaceans and the population ecology of the east Australian humpback whales. I am also interested in the population structure of humpback whales across the South Pacific region, the transmission of song as a cultural trait, acoustic surveys of marine mammals, persistent organo-pollutants in marine mammals and the ecology of dolphins in Moreton Bay. Architect, a PI and the manager of the Humpback Whale Acoustic Research Collaboration.

d. Other affiliations

Member of the Society for Marine Mammalogy
Member of the Australasian Society for the Study of Animal Behaviour

Associate member of the Acoustical Society of America
Member of the Australian Marine Science Association

e. Other relevant or professional experience

Veterinarian in small animal and mixed practice; various positions in Australia and UK 1991 – 2000.

DR REBECCA A. DUNLOP

Lecturer, Cetacean Ecology and Acoustics Laboratory School of Veterinary Science, University of Queensland, St Lucia, Qld 4072, Australia. Ph. (07) 3365 0963, Fax. (07)3365-1255 Email r.dunlop@uq.edu.au

Qualifications: B.Sc. (Environmental biology), Ph.D. (physiology) (Queens University, Belfast).

Main research interests:

Marine mammal population structure, behaviour and marine bioacoustics; particularly marine mammal communication and the effects of ambient, biological and anthropogenic noise on signalling behaviour.

Research experience and main achievements:

Ten years of research experience including four years of research in physiology (respiratory physiology, hearing physiology, stress physiology and neurophysiology in fish) and six years of research in marine mammal population, behaviour and marine bioacoustics.

Determined the ability of fish to perceive _pain' linked to an associated stress response.

Developed the first comprehensive catalogue for humpback whale non-song vocalisations and linked these vocalisations to behavioural context.

Currently working on the communication response of humpback whales to increasing background noise.

Refereed Publications since 2005.

- **Dunlop R.A**. and Mellor, A. 2008. Acoustic recordings of sperm whales (*Physeter macrocephalus*) along the North Antrim coast, Northern Ireland. Biology and Environment: Proceedings of the Royal Irish Academy 108B (3), 135 – 141.
- Noad, M.J**., Dunlop, R**., Paton, D. and Cato, D.H. Absolute and relative abundance estimates of Australian east coast humpback whales (*Megaptera novaeangliae*). Journal of Cetacean Management and Research (accepted subject to minor changes, March 2008)
- **Dunlop, R.A**., Cato, D.H and Noad, M.J. 2008. The use of acoustic communication signals in migrating humpback whales (*Megaptera novaeangliae*). Marine Mammal Science 24(3), 613 – 629.
- Smith, J.N., Noad, M.J., **Dunlop, R.A.** and Goldizen, A.W. 2008. The effect of social interactions on the singing behaviour of humpback whales (*Megaptera novaeangliae*). Animal Behaviour 76, 467 – 477.
- **Dunlop, R.A**., Noad, M. J., Cato, D.H. and Stokes, D. 2007. The social vocalization repertoire of east Australian migrating humpback whales (*Megaptera novaeangliae*). Journal of the Acoustical Society of America, 122(5), 2893 – 2905.
- **Dunlop, R.A.,** Cato, D.H. Stokes, D. and Noad, M.J. 2007. Changes in vocalization amplitude during social interactions in the humpback whale (*Megaptera noveangliae*). 17th Biennial Conference on the Biology of Marine Mammals, Cape Town, South Africa.
- Rekdahl, M. L., Noad, M. J., **Dunlop, R. A**. and Goldzien, A. 2007. Comparisons of acoustic behaviour between wild provisioned and wild unprovisioned bottlenose dolphins (*Tursiops aduncus*) in Moreton Bay, Australia. 17th Biennial Conference on the Biology of Marine Mammals, Cape Town, South Africa
- Smith, J. N., Goldizen, A. W., **Dunlop, R. A**., Cato, D. H. and Noad, M. J. 2007. Lone and escorting humpback whales vary song to favour either song propagation or display rate. 17th Biennial Conference on the Biology of Marine Mammals, Cape Town, South Africa
- **Dunlop, R.A.** and Laming, P.R. 2006. Avoidance learning in goldfish (*Carssius auratus*) and trout (*Oncorhynchus mykiss*) and the implications for pain perception. Applied Animal Behaviour Science, 97, 255 – 271.
- **Dunlop, R.A.** and Laming, P.R. 2005. Mechanoreceptive and nociceptive responses in the central nervous system of goldfish (*Carassius auratus*) and trout (*Oncorhynchus mykiss*)**.** Journal of Pain, 6 (9), 561 – 568.
- **Dunlop, R.A**., Noad, M.J. and Cato, D.H. 2005. Widespread and contextual use of social communication in migrating humpback whales. 16th Biennial Conference on the Biology of Marine Mammals, San Diego, USA, December 12-16.

Co-investigators

DR ROSS DARNELL

Dr Ross Darnell is a senior applied statistician with the CSIRO Mathematical and Information Sciences, focusing on statistical modelling of aquatic ecosystems.
Dr Ross Darnell is developing statistical models to help understand marine and freshwater ecosystems.
Projects Dr Darnell is contributing to include:

- Developing statistical models to generate species biodiversity maps of unsurveyed areas using biological surrogates. Biodiversity attributes for selected taxonomic groups, such as fishes, can be predicted from the data known about other taxonomic groups like invertebrates. This work will provide marine biologists with complete picture of national biological data.
- Ecosystem health monitoring work to provide a regional analysis of trends across freshwater, estuarine and marine habitats in South East Queensland, Australia. The project will estimate the effects of climate and land use on key freshwater and estuarine/marine performance indicators.

Dr Darnell joined CSIRO in 2008, having extensive experience as a statistical consultant in research and academic institutions in Australia and the United Kingdom (UK).
Dr Darnell has extensive experience as a statistical consultant in research and academic institutions.
He has spent time as a biometrician for New South Wales Agriculture, responsible for the statistical design and analyses of agricultural research projects undertaken in the North East region of New South Wales (NSW).
Dr Darnell has also held consultancy and lecturing roles at Queensland University of Technology, University of Southern Queensland, Newcastle University in the United Kingdom and The University of Queensland.
Academic qualifications

- Bachelor of Applied Science from The University of Queensland, Australia in 1978
- Diploma of Biometry from The University of Sydney, New South Wales, Australia in 1980
- Master of Science from the University of New England, New South Wales, in 1992
- Doctor of Philosophy from Newcastle University, United Kingdom in 2003.

Associations
Dr Darnell is a member of the following:

- Fellow, Royal Statistical Society, United Kingdom
- Member, Statistical Society of Australia and The International Biometric Society.

Professional achievements
Dr Darnell is a past president of the Queensland Branch of the Statistical Society of Australia.

DR JASON GEDAMKE

Australian Marine Mammal Centre
Australian Antarctic Division
Kingston, TAS 7050 AUSTRALIA
jason.gedamke@aad.gov.au ph: 61-3-6243-8808
Education: University of California, Santa Cruz, CA, Department of Ocean Sciences
Dissertation: Minke Whale Song, Spacing, and Acoustic Communication on the Great Barrier Reef, Australia, completed March 19, 2004
Wesleyan University, Middletown, CT
Bachelor of Arts in Biology, May 1993
Scientific research and field work: Passive Acoustic Monitoring of Southern Ocean Baleen Whales (2004-current)
Minke Whale Acoustic Ecology and Song Playback Experiments (Summers of 1997-2000, 2002)
Fin & Blue Whale Acoustic and Foraging Behavior (Springs of 1999-2000).
ATOC Northern Elephant Seal Acoustic Ecology and Response to Man-Made Noise (1996-1999)
ATOC Sound Field Measurement and Mapping (Summer 1996-1999)
Hawaiian Humpback Whale Breeding Ground Ecology (Spring 1993, 1994).
Hawaiian Humpback Whale Aerial Surveys-ATOC (Spring 1994)
NMFS Alaskan Domestic Groundfisheries Biologist (Fall-Winter 1993)
Kewalo Basin Marine Mammal Laboratory Bottlenose Dolphin Cognition (Summer 1992)

Marine mammal/endangered species impact consulting: U.S. Navy Long Endurance Low Frequency Active Sonar (LELFAS) testing—(Fall 2003)
Endangered Species Monitoring of Hopper Dredging—(Fall 2002, Summer 1996, Winter/Fall 1995)
Monitoring of Seismic Bottom Profiling, United States Geological Survey —(Fall 2001),
Monitoring of Telecommunications Cable-laying—(Summer 2001)

Peer reviewed publications:

- Gedamke, J., and S.M Robinson (in press), ―Acoustic survey for marine mammal occurrence and distribution off East Antarctica (30-80°E) in January-February 2006‖, *Deep Sea Research II*
- Thalmann, S., Gales, R., Greenwood, M., & Gedamke, J. (2008). A new technique to re-float and rescue stranded sperm whales (Physeter macrocephalus). Marine Mammal Science 24(4), pp. 949-955.
- Van Waerebeek, K., Baker, A.N., Felix, F., Gedamke, J., Iniguez, M., Sanino, G., Secchi, E., Sutaria, D., Van Helden, A., & Wang, Y. 2007. Vessel collisions with small cetaceans worldwide and with large whales in the Southern Hemisphere, an initial assessment. Latin American Journal of Aquatic Mammals.
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K. CURT S. JENNER

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Education/training:
B.Sc. Degree, General Marine Biology, University of Alberta, Canada (1984)
Master Class V Mariner (2000)
SOLAS/IFAP Helicopter Safety
Celestial Navigation
Senior First Aid

Current position: (*July 1990 - Present)*:
Principal Investigator, *CENTRE FOR WHALE RESEARCH (WESTERN AUSTRALIA) INC*
With Micheline-Nicole Jenner, I am currently conducting whale research off the west coast of Australia in collaboration with the Western Australian Museum, the University of Western Australia, Curtin University, the Australian Antarctic Division, the state Department. Of Environment and Conservation, the Federal Department of Environment Waters and the Australian Defence Department. The various studies my wife and I have conducted, focus on great whale biology and behaviour using study techniques such as habitat mapping (aerial and vessel based), acoustic surveys, long term photo-identification, satellite telemetry and genetic sampling. Since 1991, these research activities have been sponsored by oil and gas companies on the NW Shelf and have been directed towards developing mitigating techniques for development.

Relevant accomplishments:

- Discovered and mapped the Kimberley calving grounds for Group IV humpback whales
- Identified and mapped major migratory and resting areas for Group IV humpback whales on the WA coast
- Compiled an 18 year photo database of humpback whale identities (>4000), song structure and genetic samples (>475)

Relevant publications and reports:

- Jenner, K.C.S., Jenner, M.-N., 1994. A preliminary population estimate of the Group IV breeding stock of humpback whales off Western Australia. Report of the International Whaling Commission 44, 303-307.
- Jenner, K.C.S., Jenner, M-N., and K.A. McCabe (2001). Geographical and temporal movements of humpback whales in Western Australian waters. APPEA Journal 38(1):692-707.
- Jenner, K.C.S and M-N.M Jenner, 2004. Current State of Knowledge: Humpback Whale (*Megaptera novaeangliae*) Survey Report for Exmouth Gulf 1995-2004. Unpubl. report to Straits Resources. 20pp.
- Jenner, K.C.S and M-N.M Jenner, 2005. Distribution and abundance of humpback whales and other mega-fauna in Exmouth Gulf, Western Australia, during 2004/2005. Unpubl. report to Straits Resources. 24pp.
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- Jenner, K.C., Jenner, M-N., Salgado Kent, C.P., Sturrock, V.J. 2006. Recent trends in relative abundance of humpback whales in breeding stock D from aerial and vessel based surveys. SC/A06/HW21. International Whaling Commission (IWC) Scientific Committee Workshop on Status of Southern Hemisphere Humpback Whales. 4-7 April 2006, Tasmania, Australia.
- Jenner, K. C. S.; Jenner, M-N.M.;Salgado Kent, C. P.;and Bilgmann, K. (In press). Migratory Patterns in Distribution, Abundance and Behavior of Humpback Whales (*Megaptera novaeangliae*) at North West Cape, Western Australia. submitted to Marine Mammal Science, document MMSCI-2322.

Dr. HENDRIK KNIEST

Hendrik (Eric) Kniest
Professional Officer (Surveying), School of Engineering, University of Newcastle.

Academic qualifications:

Engineering Surveying Certificate, Bruce TAFE, 1978.
BSurv (Honours), University of Newcastle, 1984.
PhD in Surveying, University of Newcastle, 1991.
Certified Trimble GPS trainer, QUT Brisbane, 2001.

Current and recent research projects:

Real time theodolite tracking of marine mammals: investigation of survey techniques and software for tracking marine mammals in real time. A software package called ‗CYCLOPS TRACKER' has been developed to assist in using precise survey techniques in tracking marine mammals. The package now includes acoustic positioning and is being expanded to include photogrammetric methods (cameras), electronic compass, database/GIS functions and vessel (including aircraft) based surveys.

Semi-automatic methods for whale fluke matching. Development of new software (FLUKE MATCHER) to assist in matching of whale fluke photographs. The system involves using photogrammetric techniques to first rectify photographs for scale and rotations, the measurement of numerous feature characteristics and a variety of flexible matching techniques.

Selected publications:

- Mitchell, H. and Kniest, E, (1999) ‗Digital Photogrammetry and Microscope Photographs', **Photogrammetric Record, 16(94)**: 695-704.
- Kniest, E. and Paton, D., (2000) ‗Real Time tracking of Humpback Whales', **Humpback Whale Conference 2000, Brisbane**.
- Kniest, E. and Paton, D., (2001) ‗Temporal GIS for Marine Mammal Research', **14th Biennial Conference on the Biology of Marine Mammals, Vancouver**.
- Chandler J.H., Fryer J.G. and Kniest H.T., (2005) ‗Non-Invasive Three-Dimensional Recording of Aboriginal Rock Art Using Cost-Effective Digital Photogrammetry', **Rock Art Research, 22(2):** 119-130.
- Kniest, E., Burns, D. and Harrison, P. (2009) ‗Fluke Matcher: a computer-aided matching system for humpback whale (Megaptera novaeangliae) flukes', **Marine Mammal Science,** (under review).
- **Thesis**
- Kniest, H.T. (1990). ‗Photogrammetry through an air-water interface', **Ph.D. Thesis**, University of Newcastle, Callaghan, 185 pp.

MR JOHN NOAD

Academic qualifications:
B. Sc. (Hons Physics), University of Queensland 1963
P/G Diploma in Process Optimisation, University of Queensland 1967
M. Sc. (Computer Science), University of Queensland 1972
Some positions held:
Director, Prentice Computer Centre, University of Queensland 1988 – 1991
Director, Department of Computing Services, Queensland University of Technology, 1991 – 1998
Retired 1998 -
Experience with Humpback Whale Research
I have been involved with humpback whale research since the mid-1990s, working on various projects since then including the major HARC projects in 2002 – 2004. Most recently was the HARC field season in 2008. My work in this field includes:

- Design, building and running the computer networks used for recording information
- Some advice on the modifications to software to use the network
- Design and building various items of equipment used in the project
- Preparation, testing and maintenance of field equipment, particularly hydrophone buoys, wireless antennas, solar panels etc.
- Involvement in the planning of project developments.
- Work on developing new networks for more extensive data gathering including connections to vessels.

MR DAVID PATON

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E-mail: dave@blueplanetmarine.com
DOB 11 September 1960, Australian citizen
Membership of learned societies and affiliations: Executive member of the South Pacific Whale Research Consortium, The Society for Marine Mammalogy, The Australian Marine Sciences Association
Qualifications:
My qualifications and academic experience include:

- Ph.D. Candidate, School of Environmental Science and Management, Southern Cross University, Lismore. Currently enrolled part time. Title of thesis ―Population dynamics and movement patterns of humpback whales in the South Pacific‖.
- Bachelor of Science, Marine Biology and Zoology, James Cook University, Townsville, 1987.

David Paton is an experienced environmental manager and cetacean biologist with over 25 years' experience throughout Australia, the South Pacific, Southern Ocean (Antarctic waters), USA and Canada in marine and terrestrial protected area management, environmental planning and assessment, research and monitoring. His extensive field experience includes the identification of a diverse range of cetacean species, coordinating whale, dolphin, turtle and sea bird research, monitoring and assessing anthropogenic impacts.

David is the Director of Blue Planet Marine, Environmental Research and Consulting Company. David was the founding Director of the Southern Cross Centre for Whale Research located at Southern Cross University. While at Southern Cross University, in recognition of his experience, he was awarded the title of Adjunct Associate Professor. David is currently completing his PhD in marine mammal science. His research includes the determination of the current population status and recovery trends of humpback whales on the east coast of Australia and the Oceania region, the development of a range of survey techniques for surveying marine mammals and monitoring anthropogenic activities. David has recently been contracted by the Australian Government (through the South Pacific Whale Research Consortium – where he is a founding member, Executive officer and the Science officer) to write an Oceania Humpback Whale Recovery Plan.

Complementing this experience David also has extensive experience with strategic planning and environmental assessment, after working as a Senior Policy Officer in the Marine Planning Section and the Cetacean Policy Section of the Commonwealth Department Environment and Heritage. In addition David was also an Operations Manager in the NSW National Parks and Wildlife Service and a Senior Ranger with Qld National Parks and

Wildlife Service based in the Great Barrier Reef Marine Park for an extended period. David has extensive project management experience in a range of large multidisciplinary projects throughout the world. He also has extensive experience as the Occupational Health and Safety Officer for a number of organisations and is familiar with the relevant legislation, implementation and review of Health and Safety issues in the work place.

David's areas of expertise include:

- Marine mammal identification, research, monitoring and management of anthropogenic activities;
- The management of commercial and recreational activities;
- Project coordination, including development, implementation, monitoring and evaluation;
- Staff supervision and communication, liaison, facilitation and negotiation;
- Environmental interpretation;
- Environmental surveys including survey design, evaluation and implementation;
- Wildlife and landscape photography (including underwater photography).

David has over 50 scientific papers, major reports and other papers, 11 of which are scientific publications in peer reviewed international journals.

DR. CHANDRA P. SALGADO KENT

Centre Marine Science and Technology, Curtin University, G.P.O. Box 1987; Perth, WA 6845; Australia; Tel: +61 (08) 9266 3104; c.salgado@cmst.curtin.edu.au

Nationality: USA / Venezuela; Citizenship: USA, Australia; Birth place: Caracas, Venezuela.

General experience: Main research focus during the last five years includes anthropogenic impacts on marine animals (including noise); vocalisation, distribution, and migration patterns of marine mammals; and statistical analysis of biological data. Prior to this, work in the field of marine ecology spanned a period of 8 years. A vast number of projects undertaken have been large and interdisciplinary involving a large number of personnel conducting a multitude of tasks, and thereby requiring high-level management and organisational skills for their efficient and successful completion.

Education: BSc Biology (NMT, USA), MSc Marine Biology (FIT, USA), PhD Marine Ecology (CDU, Australia).

Recent Assignments: Research Fellow since 2003 – Curtin University of Technology, Centre for Marine Science and Technology, Perth, Australia - Recent research projects have included: assessment of impacts to fish hearing and behaviour from noise produced during seismic surveys carried out by oil and gas industries, assessment of potential impacts to marine animals from dredging and marine construction noise, assessment of impacts from noise produced by oil and gas production facilities on marine mammals, and censusing great whale population using passive acoustics.

Recent (last 5 years) publications, reports, workshops and conferences:

- Crabtree, B. and Salgado Kent, C.P. 2007. In press. A Study of the Australian Sea Lion (*Neophoca cinerea*) and Human Disturbance on Carnac Island, Australia. Tourism in Marine Environments.
- Salgado Kent, C.P. and McCauley, R.D. 2006. Preliminary report and summary of work to Dec 2006 to ascertain if hearing damage has occurred in wild gold band snapper due to seismic survey exposure. CMST Report No 2006-54.
- Salgado Kent, C.P. and McCauley, R.D. 2006. Cumulative noise produced by oil and gas production on the North West Shelf, Western Australia. CMST Report No 2006-49.
- Salgado Kent, C.P. and McCauley, R.D. 2006. Underwater noise impacts assessment - Port of Melbourne Channel Deepening Project. CMST Report No 2006-19.
- McCauley, R. and Salgado Kent, C.P. 2006. Expert Panel: "A Atividade Sismica e o Ambiente Marinho" (Seismic Impacts on the Marine Environment). Rio de Janeiro, Brazil.
- R. McCauley, C.P. Salgado Kent, J. Bannister, C. Burton. 2006. Estimates of pygmy blue whale abundance in the Perth Canyon, based on acoustic census techniques. Abstract. Department of Environment and Heritage Whale Workshop, Adelaide, Australia.
- Salgado Kent, C.P. and McGuinness, K.A. 2006. "A comparison of methods for estimating relative abundance of grapsid crabs". Wetlands Ecology and Management. Vol. 14 (1): 1-9.
- McCauley, R.D., Salgado Kent , C.P., Burton, C.L.K., Jenner, C. 2006. "Blue Whale Calling in Australian Waters", The Journal of the Acoustical Society of America, Vol. 120, Issue 5, pt 2, pp 3266.
- Salgado Kent, C.P. 2005. Coordinated workshop on ―Impacts of Noise on Marine Animals‖. Australian Acoustical Society Conference, Bussleton, Australia.

- Jenner, K.C., Jenner, M.N., Salgado Kent, C.P., Sturrock, V. and Bilgmann, K. In prep. Migratory Patterns in Distribution, Abundance, and Behaviour of Humpback Whales (*Megaptera novaengliae*) at North West Cape, Western Australia. Marine Mammal Science.
- McGuinness, K.A. and Salgado Kent, C.P. (Submitted – in review). Spatial and temporal variation in relative numbers of grapsid crabs in northern Australian mangrove forests. Journal of Experimental Marine Biology and Ecology.
- Salgado Kent, C.P. and McGuinness, K.A. (Submitted – in review). Feeding selectivity of grapsid crabs from northern Australian mangrove forests. Marine and Freshwater Research.
- Salgado Kent, C.P and McGuinness, K.A. 2006. A comparison of methods for estimating relative abundance of grapsid crabs. *Wetlands Ecology and Management*. Vol. 14 (1): 1-9.
- McCauley, R.D. and Salgado Kent, C.P. 2005. Curtin University Underwater Sounds Catalogue. CMST Report No. R2005-11.
- McCauley, R.D., Salgado-Kent, C., Cato, D.H., Jenner, C&M-N., Bannister, J.L., Burton, C.L.K. 2005. "Great Whale Vocalisations along the Western Australian Coast - Their use in Biological Studies" Transport Noise and Vibration: The New Millennium, Proceeding of the Annual Conference of the Australian Acoustical Society, 3-5 November, 2005, pp 289, Acoustics 2004.
- Jenner, C. and M-N., Sturrock, V. and Salgado Kent, C. 2005. Summary Report 2000-2005. Whale Migration Patterns in the North West Cape Region. Report for Woodside Energy and BHP Billiton Petroleum.
- Salgado Kent, C.P and McCauley, R. 2004. An Analysis of Blue Whale (*Balaenoptera musculus*) Call Variations from South-Western Australia. *Australian and Marine Sciences Association, Hobart, Australia.*
- McCauley, R., Bannister, J., Burton, C., Jenner, C., Rennie, S. and Salgado Kent, C. 2004. "Western Australian Exercise Area Blue Whale Project - Final Summary Report - Milestone 6", Centre for Marine Science & Technology, Report #2004-29.
- Jenner, K.C., Jenner, M.N., Salgado Kent, C.P., and Bilgmann, K. 2003. Relative Abundance and Distribution of Southern Hemisphere Group IV Humpback Whales (*Megaptera novaengliae*) during their Northern and Southern Migration at North West Cape, Western Australia. *Australian and Marine Sciences Association, Brisbane, Australia.* 7

Appendix
Papers on Australian humpback whales

Migrations /biology/life history – papers, book chapters,

- Anderson, M.J., Hinten, G., Paton, D. and Baverstock, P.R. (2001) A model for the integration of microsatellite genotyping with photographic identification of humpback whales. Memoirs of the Queensland Museum 47(2): 452-457.
- Bannister, J.L. (1985) Southern right (Eubalaena australis) and humpback (Megaptera novaeangliae) whales off Western Australia: some recent aerial survey work. In Ling, J.K. and Bryden, M.M. ―Studies of Sea Mammals in South Latitudes‖ South Australian Museum, Adelaide.
- Bannister, J.L. and Hedley, S.L. 2001. Southern Hemisphere Group IV humpback whales: their status from recent aerial surveys. Memoirs of the Queensland Museum 47(2):587-598.
- Brown, M. and Corkeron, P. 1995. Pod characteristics of migrating humpback whales (*Megaptera novaeangliae*) off the east Australian coast. Behaviour 132(3-4):163-179.
- Brown, M.R., Corkeron, P.J., Hale, P.T., Schultz, K.W., and Bryden, M.M. 1995. Evidence for a sex-segregated migration in the humpback whale (*Megaptera novaeangliae*). Proceedings of the Royal Society of London - Series B: Biological Sciences 259:229-234.
- Bryden, M. M. (1985). Studies of humpback whales (Megaptera novaeangliae), Area V. In Studies of Sea Mammals in South Latitudes, ed. by J. K. Ling & M. M. Bryden. South Australian Museum, Adelaide, pp. 115-23.
- Bryden, M.M., Kirkwood, G. P., & Slade, R. W. (1990). Humpback whales, Area V. An increase in numbers off Australia's east coast. In Antarctic Ecosystems. Ecological Change and Conservation, ed. by K. R. Kerry & G. Hempel. Springer-Verlag, Berlin & Heidelberg, pp.271-7.
- Burton, C.L.K. 1991. Sighting analysis and photo-identification of humpback whales, off Western Australia, 1989. Memoirs of the Queensland Museum 30(2):259-270.
- Burton, C.L.K. 2001. Historical and recent distribution of humpback whales in Shark Bay, Western Australia. Memoirs of the Queensland Museum 47(2): 599-611.
- Chittleborough, R.G. 1953. Aerial observations on the humpback whales, *Megaptera nodosa* (Bonnaterre), with notes on other species. Australian Journal of Marine and Freshwater Research 4:219-226.
- Chittleborough, R.G. 1954. Studies on the ovaries of the humpback whale, *Megaptera nodosa* (Bonnaterre), on the Western Australian coast. Australian Journal of Marine and Freshwater Research 5:35-63.
- Chittleborough, R.G. 1955a. Aspects of reproduction in the male humpback whale, *Megaptera nodosa* (Bonnaterre). Australian Journal of Marine and Freshwater Research 6:1-29.
- Chittleborough, R.G. 1955b. Puberty, physical maturity, and relative growth of the female humpback whale, *Megaptera nodosa* (Bonnaterre), on the Western Australian coast. Australian Journal of Marine and Freshwater Research 6:315-327.
- Chittleborough, R.G. 1958. The breeding cycle of the female humpback whale, *Megaptera nodosa* (Bonnaterre). Australian Journal of Marine and Freshwater Research 9(1):3-18.
- Chittleborough, R.G. 1959. Determination of age in the humpback whale, *Megaptera nodosa* (Bonnaterre). Australian Journal of Marine and Freshwater Research 10:125-143.
- Chittleborough, R. G. (1965). Dynamics of two populations of the humpback whale, Megaptera novaeangliae (Borowski). Aust. J. Mar. Freshwat. Res., 16, 33-128.
- Corkeron, P.J., Brown, M., Slade, R.W., and Bryden, M.M. 1994. Humpback whales, *Megaptera novaeangliae* (Cetacea: Balaenopteridae), in Hervey Bay, Queensland. Wildlife Research 21:293-305.
- Corkeron, P.J. 1995. Humpback whales (*Megaptera novaeangliae*) in Hervey Bay, Queensland: Behaviour and responses to whale-watching vessels. Canadian Journal of Zoology 73:1290-1299.
- Corkeron, P.J., Brown, M., Slade, R.W., and Bryden, M.M. 1994. Humpback whales, Megaptera novaeangliae (Cetacea: Balaenopteridae), in Hervey Bay, Queensland. Wildlife Research 21:293-305.
- Dawbin, W. H. (1956). The migrations of humpback whales which pass the New Zealand coast. Trans. R. Soc. N.Z., 84, 147-96.
- Dawbin, W.H. 1960. An analysis of the New Zealand catches of humpback whales from 1947-1958. Norsk Hvalfangst-Tidende 49:61-75.
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Norsk Hvalfangsttid., 3, 68-78.

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- Dawbin, W.H. (1997). Temporal segregation of humpback whales during migration in southern hemisphere waters. Mem. Qd Mus. 42 (1): 105-138. Forestell, P.H., Paton, D.A., Hodda, P. and Kaufman, G.D. (2001). Observations of a hypo-pigmented humpback whale, *Megaptera novaeangliae*, off east coast Australia: 1991-2000. Mem. Qd Mus. 47 (2): 437-449.
- Garrigue, C., Forestell, P., Greaves, J., Gill, P., Naessig, P., Patenaude, N.M., and Baker, C.S. 2000b. Migratory movements of humpback whales (Megaptera novaeangliae) between New Caledonia, East Australia and New Zealand. Journal of Cetacean Research and Management 2(2):111-115.
- Gill P.C. and C.L.K. Burton. (1995). Photographic resight of a humpback whale between Western Australia and Antarctic Area IV. *Marine Mammal Science* 11(1): 96-100.
- Janetzki, H.A., and Paterson, R.A. Aspects of humpback whales, *Megaptera novaeangliae*, calf mortality in Queensland. Mem. Qd Mus. 47 (2): 431-435.
- Jenner, K.C.S., Jenner, M-N., and K.A. McCabe (2001). Geographical and temporal movements of humpback whales in Western Australian waters. APPEA Journal 38(1):692-707
- Kaufman, G.D., Smultea, M.A., and Forestell, P. 1987. Use of lateral body pigmentation for photographic identification of east Australian (Area V) humpback whales. Cetus 7:5-13.
- Noad, M.J. and Cato, D.H. (2007) Swimming speeds of singing and non-singing humpback whales during migration. *Marine Mammal Science*, 23, 481 – 495.
- Noad, M.J., Dunlop, R., Paton, D. and Cato, D.H. Absolute and relative abundance estimates of Australian east coast humpback whales (*Megaptera novaeangliae*). Journal of Cetacean Management and Research (in press)
- Paterson, R. (1980). Encouraging sightings of humpback whales off east coast. Aust. Fish., 40(4), 30-3.
- Paterson, R. (1984). Migration patterns of humpback whales (Megaptera novaeangliae) in the waters adjacent to Moreton and North Stradbroke Islands. In Focus on Stradbroke, ed. by R. J. Coleman, J. Covacevich & P. Davie. Boolarong, Brisbane, pp.342-7.
- Paterson, R. & Paterson, P. (1984). A study of the past and present status of humpback whales in east Australian waters. Biol. Conserv., 29, 321-343.
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- Paterson, R.A. (1991) The migration of humpback whales Megaptera novaeangliae in east Australian waters. Mem. Qd Mus. 30 (2) : 333-341.
- Paterson, R.A. and Van Dyck, S. (1991) Studies of two humpback whales, *Megaptera novaeangliae*, stranded at Fraser Island, Queensland. Mem. Qd Mus. 30 (2) : 343-350.
- Paterson, R. A., Quayle, C. J., and Van Dyck, S. M. (1993). A humpback whale calf and two sub-adult dense-beaked whales recently stranded in southern Queensland. Mem. Qd Mus. 33(1), 291-7.
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- Paxton, C.G.M., Hedley, S.L. and Bannister, J.L. (in press) Group IV Humpback whales: their status from aerial and land-based surveys off Western Australia, 2005. *Journal of Cetacean Research and Management, Special Issue on Humpback Whales.*
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Acoustics, related behaviour, BRS papers, book chapters

- Cato, D.H. 1984. Recording humpback whale sounds off Stradbroke Island. In: Focus on Stradbroke, ed. R.J. Coleman, J. Covacewich and P. Davie. Boolarong Publications: Brisbane. Pp.285-290.
- Cato, D.H. (1991) ―Songs of humpback whales: the Australian perspective.‖ *Mem. Qd Mus.* 30(2), 278-290.
- Cato, D.H., Paterson, R. and Paterson, P. (2001) Vocalisation rates of migrating humpback whales over 14 years. *Memoirs of the Queensland Museum* (special issue on humpback whales), 47(2) 481-489.
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- Dunlop. R.A., Cato, D.H. & Noad, M.J. (2008) Non-song acoustic communication in migrating humpback whales (*Megaptera novaeangliae*). *Mar. Mamm. Sci.* 21, 613-629.
- Helweg, D.A., Cato, D.H., Jenkins, P.F., Garrigue, C., and McCauley, R.D. 1998. Geographic variation in South Pacific humpback whale songs. *Behaviour* 135:1-27.
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