GREAT BARRIER REEF
MARINE PARK AUTHORITY

RESEARCH PUBLICATION NO. 75

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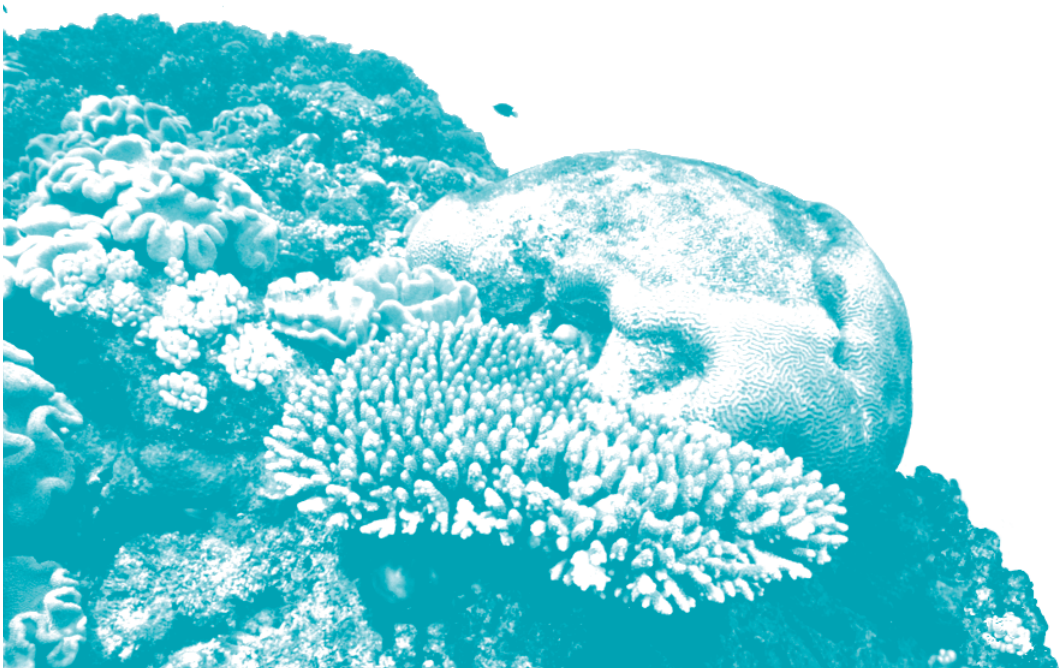
Mary C. Hamilton



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SUMMARY

Aircraft overflights and associated noise in National Parks is an environmental management issue which is becoming increasingly important as growth in the tourism industry occurs in Australia and world-wide. The protection of natural quiet is arguably as crucial as the protection of wildlife and clean water.

As a result of issues identified regarding use of the Whitsunday Islands Area, the Great Barrier Reef Marine Park Authority (GBRMPA) commissioned a social survey of visitors to Whitehaven Beach in the Whitsunday Islands. The survey, undertaken in early 1999, aimed to assess visitor use and experience of the area, while evaluating the influence of aircraft and watercraft on peoples use and amenity (Ormsby and Shafer, 1999). Whitehaven Beach is classified by GBRMPA as a sensitive site but receives a high proportion of the visitors to the Great Barrier Reef Marine Park (the Marine Park, GBRMP), and World Heritage area (GBRWHA). This study aims to complement the social survey providing quantitative information describing actual levels of aircraft activity and noise along Whitehaven Beach, particularly, in relation to the four Recreation Opportunity Spectrum (ROS) settings designated along it. Other anthropogenic sources of noise and activity were also assessed as a function of setting. The main data was collected at sites situated central to each of the ROS settings along Whitehaven Beach. Figure 1.0 details the study site.

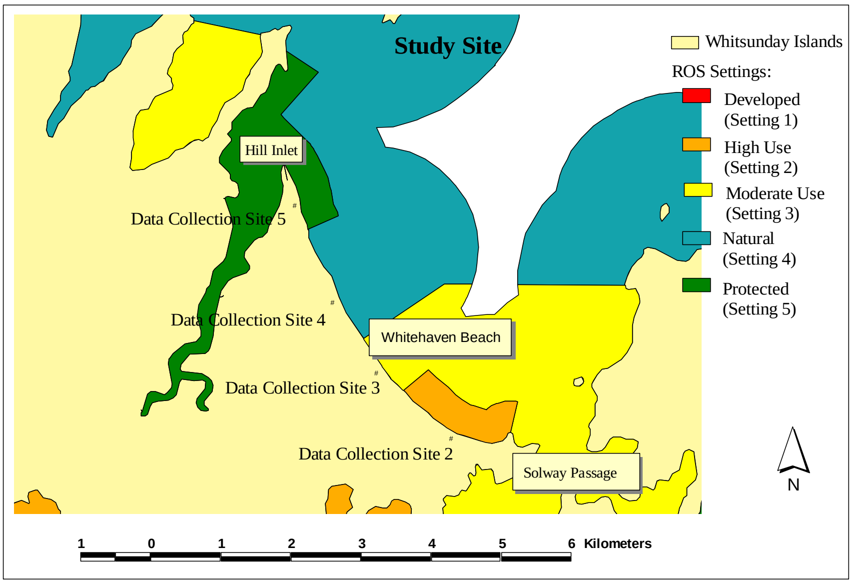

Figure 1.0. Detail of the study site

The key findings of this study are summarised below:

Aircraft Activity -

Overall site 2 experienced the fewest aircraft events followed by sites 5, 4 and 3. The most common aircraft at all sites were seaplanes followed by helicopters. Site 2 received the greatest within site proportion of seaplane events and site 5 the greatest within site proportion of helicopter events. The morning was the busiest time of day peaking between 11:30 and 12:30 with an average of 4.7 - 6.2 flights per hour over all sites. Aircraft were observed between 07:00 and 17:00. Seaplane events were most common in the morning. Other event types did not show a trend of activity relative to time of day. 71% of all aircraft events at Whitehaven Bay affected 3 or 4 of the sites.

Natural Sound Levels -

Natural sound levels were lower at site 5 than at the other three sites. The overall average natural day-time sound level on the landward side of Whitehaven Beach is calculated to be 57dBA. However, the actual average is thought to be in the range of 50 - 55dBA (based on comparative measurements made with a more sensitive sound meter). These results are consistent with recordings made in the USA and predictions for sites situated close to surf and exposed to wind (Fidell et al. 1990; Bowlby et al. 1990; US Forest Service 1992).

Aircraft Sound Levels -

At sites 3, 4 and 5, 95% of aircraft events registered above background sound levels and at site 2, 85% did so. Maximum decibel levels recorded for aircraft events ranged from 54dBA - 98dBA over all sites. The most commonly recorded maximums at all sites were within the range of 60-64dBA. Site 4 recorded the highest average Lmax (68.8dBA) followed by sites 3, 2 and 5 (59.9dBA).

The noisiest times of day varied between sites. Seaplane takeoffs were the loudest recorded event type followed by helicopter flyovers associated with a landing or takeoff (low flying helicopters). Military jets which reportedly over fly Whitehaven but which were not observed during the course of this study are expected to cause the highest sound readings of all aircraft visiting Whitehaven. A strong negative correlation (significant at $\alpha = 0.01$) was established between increasing distance and increasing sound level for seaplane takeoffs.

Sites 3 and 4 recorded the longest duration of aircraft sound above average background sound levels and sites 2 and 5 recorded the shortest duration. The average duration of aircraft sound levels above background sound levels is calculated to be 57 seconds. The longest recorded duration was 420 seconds.

Other Anthropogenic Influences -

The majority of the people on the beach at 10:30 and 14:00 were in setting 2. Few people were recorded in any setting at 17:00. A similar number of watercraft were recorded passing through each setting. However, the number of watercraft events considered loud enough to warrant recording was much higher at site 2 than at all other sites. The highest recorded watercraft sound level was 79dBA and the longest recorded duration above average background sound level was 820 seconds (both were recorded at site 2). All types of watercraft occurred in all settings and included jet-skis, speed boats and large hydrofoils.

Notably the results of this study represent the lower levels of aircraft noise and activity experienced at Whitehaven Beach over a year.

It is concluded that, in terms of aircraft activity and noise levels along Whitehaven Beach, a trend inconsistent with that predicted by the definitions of the ROS settings is apparent. The high use zone receiving the lowest levels of use and noise exposure and the moderate and natural use zones receiving the highest levels of use and noise. This appears to be related to planning for the area as aircraft landing zones have been established in settings designated to receive minimal aircraft activity while the ROS settings themselves comprise small spatial areas. However, there also appears to be a problem of compliance with restrictions on access to settings. For example, aircraft takeoffs occurred beyond designated zones as did motorised water sports (such as jet-skis). For the anthropogenic influences of watercraft and people, the high use setting received the most use, consistent with expectations. However, a gradient in human and watercraft use in line with the definitions of the ROS settings was not apparent between the other settings. Aircraft were found to register the highest decibel levels of any sound source on the beach with peaks ranging from 0 - 40dBA above average natural sound levels. Yet, watercraft potentially cause an equivalent or greater noise impact, due to emitting noise for longer durations.

It is recommended that GBRMPA continue working toward comprehensive aircraft management policy development for the Great Barrier Reef Marine Park and that this study be used as partial justification for a more comprehensive baseline and monitoring study of aircraft and watercraft at Whitehaven Bay and in the Whitsunday Islands generally. Any future research should meet Australian Standards for sound measurement and therefore be able to be used for decision making with legal implications.

Prior to undertaking further research, it is recommended that GBRMPA consider:

- Its expectations for the ROS settings throughout the Marine Park in terms of aircraft / watercraft activity and noise.
- Appropriate current and future levels of use at Whitehaven Beach particularly in light of the beach's designation as a sensitive site.
- The possibility of developing dose response curves for the area.
- The need for ROS planning on a larger geographic scale than that at Whitehaven Bay.

As part of future research, it is recommended that GBRMPA further investigate:

- Flight paths and takeoff positions which would result in the most acceptable impact within the ROS settings along Whitehaven Beach and in the Whitsunday Islands generally.
- Potential noise mitigation measures including distance (height) of the sound source from the listener, phasing in the use of quieter aircraft technology and the potential for developing Fly Neighbourly Policies with local operators.

INTRODUCTION

Background

Aircraft Noise Pollution

Since the onset of the industrial age, and the concurrent increase in noise in our environment, natural quiet has become an ever scarcer resource. Yet, natural quiet is as important a resource as clean water, clear air and wildlife (Lee 1994; Nadis 1994; Berglund et al. 1996; McCain 1997; Udall 1997). Noise pollution is among the most serious environmental problems faced by countries belonging to the Organisation for Economic Co-operation and Development. It is estimated that a third of the inhabitants of these countries are exposed to unacceptably high daily doses of noise due primarily to road and airport traffic and industry (Angus 1994; Bequette 1994; Blanchard 1998; Batz 1998). Other than destroying natural sound environments, noise has been linked to various health conditions including, hearing impairment, learning impairment, annoyance, hypertension and cardiovascular disease (Godlee 1992; Angus 1994; Trong-Neng Wu et al. 1995; Bond 1996). Noise has also been linked to behavioural changes in other species (Hicks et al. 1987; Stockwell et al. 1991; Maier et al. 1998). Although many of the impacts of noise, both on humanity and on the ecosystem in which we live, are yet to be fully defined and discerned, there is little doubt that they occur.

Aircraft noise pollution in National Parks and other protected areas as an impact on human recreational use, is a growing issue, which has only recently started to be addressed. To date few other studies describing aircraft activity and sound levels in protected areas are known to have been conducted in Australia. Although several social surveys, addressing user perceptions of aircraft noise in protected areas, have been undertaken and published in Australia. Conversely, since the late 1980's the United States of America (USA or US) has been active in undertaking studies aimed at determining both the social impacts of aircraft and the levels of aircraft use and noise in its National Parks and Forests. Studies investigating aircraft noise in the vicinity of airports in urban areas have been undertaken both in Australia and overseas. However, because of the context of the noise, this issue is quite different to that of aircraft noise in National Parks.

The Great Barrier Reef Marine Park

The Great Barrier Reef Marine Park (GBRMP, the Marine Park) is currently the largest Marine Park in the world comprising an area of 347 800km^2 and stretching along the Queensland coast from Cape York in the north to Frazer Island in the south (Wachenfeld et al. 1998). The Marine Park is also a World Heritage site and experiences a diverse range of uses including: recreation and tourism; commercial fishing; shipping; scientific research; traditional hunting and mariculture. Tourism is the largest industry in the Marine Park and growth in the tourism industry is expected to continue into the future (Campbell 1993; Driml 1994; Ormsby and Shafer 1999; UNESCO, 1999). A total of 2.2 million people were estimated to have visited the park in the 1994 / 1995 financial year (Valentine et al. 1997). While between 1991 and 1995, aircraft tourist operations in the Marine Park increased by approximately 45 percent (Adami and Jennings 1995). The Whitsunday Islands are located within the Marine Park north of Mackay City between latitudinal co-ordinates 20°00'S and 20°45'S. They constitute 1% of the total area of the Marine Park but are one of the most important tourist destinations within it, receiving a third of all visitors to the Marine Park and thus are likely to be particularly affected by growth in the tourism industry. Within the Whitsunday Islands, Whitehaven Beach is regarded as one of the most popular tourist destinations and received over 80,000 visitors during the 1994 / 1995 financial year (Dutton et al. 1984; GBRMPA 1998).

The Great Barrier Reef Marine Park Authority (GBRMPA, the Authority) is the statutory body in charge of managing use of the Marine Park under the directive of the *Great Barrier Reef Marine Park Act, 1975.* Management of the Whitsundays Region of the Marine Park is also directed by the Central Section Zoning Plan (1987), and the Whitsundays Plan of Management (1998). Day to day management of the Whitsunday Islands occurs through joint management arrangements with the Queensland Department of Environment. In order to manage use of the Marine Park, Recreation Opportunity Spectrum (ROS) settings have been designated within it and restrictions on activities and access to setting areas have been established (GBRMPA 1998). Aircraft in the Marine Park are also governed by the *Air Navigation Act, 1920* and the *Civil Aviation Act, 1988.* Under the *Great Barrier Reef Marine Park Act, 1975*, the GBRMPA may issue permits with conditions regulating aircraft in airspace within the Marine Park (includes airspace to a height of 3000ft / 915m) provided that restrictions imposed by the GBRMPA may be legally compiled with under other legislation, such as the *Civil Aviation Act, 1988.* However, the Civil Aviation Authority (CAA) promote the use of 'Fly Neighbourly Policies' between environmental management organisations and the local operators (Adami and Jennings 1995). Fly Neighbourly Policies are a voluntary code of practice and do not take precedence over CAA or defence regulations. Based on overseas experience, the CAA request that pilots maintain a minimum altitude of 2000ft (the altitude limit is considered to be potentially negotiable) above environmentally sensitive areas. To date, Fly Neighbourly Policies have been used in several parks in Australia and are judged to have been reasonably successful (Adami and Jennings 1995). According to sources at GBRMPA, they were not in use in the Marine Park in 1999 (Innes, *pers. comm.*, 1999).

The Authority has identified a range of issues which need to be resolved in order to better manage use of the Whitsunday Islands area. These include: "managing intensive use to ensure it does not devalue visitor experience at popular destinations" and "minimising disturbance to users of the Area caused by noisy and intrusive activities" (GBRMPA 1998, p.11). The need for management of the Marine Park for the purpose of human amenity is also discussed by Adami and Jennings (1995) who claim that while past issues, notably the need to regulate aircraft near seabird colonies, are still relevant, a new issue needing to be addressed in relation to aircraft is that of human amenity. They recommend that the Authority undertake a study to determine the affects of aircraft activity on human users at sites located in the various settings of the ROS. They also recommend that a detailed analysis of tourist flight operations including their routes and visitation frequencies be undertaken in order to more accurately assess the impact of aircraft in the Marine Park.

As a result of issues identified regarding use of the Whitsunday Islands Area, the GBRMPA contracted environmental psychology consultants Jayne Ormsby and Scott Shafer to undertake a social survey of visitors to Whitehaven Bay. The survey, undertaken in early 1999, aimed to assess visitor use and experience of the area, while evaluating the influence of aircraft and watercraft on peoples use and amenity (Ormsby and Shafer 1999).

PURPOSE

The purpose of this research is to provide quantitative information describing actual levels of aircraft activity and sound along Whitehaven Beach, particularly in relation to the four ROS settings, designated along the beach. The results of this research are intended for use by the Authority to complement Ormsby and Shafer's social survey. One of the intended outcomes of this study is to help determine whether or not a more complete baseline study, with the potential to lead into a monitoring program of aircraft activity at Whitehaven Beach and the Whitsunday Islands in general, is warranted.

AIMS AND OBJECTIVES

Aim

To assess aircraft sound and activity in the four recreational opportunity spectrum settings along Whitehaven Beach.

Objectives

1. To describe and establish aircraft activity within each of the ROS settings along Whitehaven Beach.
2. To describe and establish aircraft sound levels relative to natural sound levels within each of the ROS settings along Whitehaven Beach.
3. To compare aircraft noise and activity with other types of anthropogenic noise and activities along Whitehaven Beach.
4. To make recommendations for future noise monitoring studies.

A REVIEW OF RELATED STUDIES

Most related studies involving the measurement of aircraft noise and activity in relation to human recreational use in National Parks have been undertaken in the United States of America. Related studies undertaken to date in Australia have been primarily social surveys or have addressed the impacts of noise on other species.

Studies Undertaken in Australia

Brown (1986) undertook a study to determine how seaplanes affect people's perceptions of their experience on Green Island, GBRMP. Brown (1986) found that for 95% of visitors, seaplanes were an acceptable part of their experience. For the 5% who found that seaplanes decreased their enjoyment of the island, the main reasons were noise and beach conflicts. The proportion of people who found that seaplanes decreased their enjoyment increased with an increase in the frequency of seaplane operations. Brown (1986) also took spot sound level measurements at various points around Green Island to determine daytime background sound levels and seaplane sound levels. Brown (1986) used the metrics 'Lmax' and 'duration above background' as means of assessing the intrusiveness of seaplane noise. For background sound levels as a result of waves, wind and people, peaks recorded ranged from 40dBA - 54dBA. Peak sound levels made by seaplanes always occurred during takeoff and were recorded in the range of 58dBA - 76dBA. During takeoff seaplane sound levels were concluded to generally be 10 - 20 dBA above background sound levels for a duration of 25 seconds.

Dellora et al. (1984) investigated conflict between types of recreationists (bushwalkers, picnickers and recreational vehicle users) in Victoria, Australia, and found trail bike noise to be the primary cause of concern. Beal (1994) reports on a study done in Queensland on camper's attitudes to noise and regulations in National Parks. The study did not specifically address the issue of aircraft noise. However, it did find that campers were most intolerant of technology related noise, specifically car, radio and television noise.

Mathers (1987) did an honours dissertation from Griffith University on the effect of aircraft noise on the behaviour of *Sterna bergii* (Crested Turns) on islands in the GBRMP and concluded that aircraft noise had a significant effect on their behaviour. Hicks et al. (1987) investigated seaplane and vessel disturbance of nesting seabird colonies on Michaelmas Cay. They concluded that seaplane operations had a significantly greater likelihood of resulting in seabird disturbance than vessel operations.

Ormsby and Shafer (1999) undertook a social survey of visitors to Whitehaven Bay, Whitsunday Island. They aimed to assess visitor use and experience of the area, while evaluating the influence of aircraft and watercraft on visitors' use and perceived amenity of the beach. Data was collected during 16 survey trips carried out between mid-March 1999 and mid-April 1999. Survey trips were undertaken aboard tour craft visiting Whitehaven Beach as part of their regular operation. Respondents surveyed spent an average of 2 hours on Whitehaven Beach. Ormsby and Shafer (1999) concluded that only approximately 10% of people were adversely affected by aircraft, watercraft or crowding on Whitehaven Beach and that the natural and scenic qualities of Whitehaven Beach were attributes that visitors received the most enjoyment from.

They observed ROS Setting 2 to be the most frequently visited setting by people and watercraft. They recorded an average of 137 people, 2 large vessels, 3 medium boats, 2 small boats and 4 yachts in setting 2 during their survey trips. An average of 1.3 seaplane overflights and 1.0 helicopter overflight were observed during their survey trips and no difference in the perception of aircraft activity was found between the settings visited. However, limitations experienced during data collection are expected to have affected results. Ormsby and Shafer's (1999) data was collected during a low season of use at Whitehaven Beach while weather conditions were unfavourable. Only 12% of the visitors sampled experienced fine weather. Furthermore, an equal cross representation of respondents from small and large tour vessels visiting a range of ROS settings was not obtained. 86% of respondents visited Setting 2 (high use setting), 11% visited Setting 3 (moderate use setting) and 3% visited Setting 5 (protected setting) while 73% of visitors surveyed traveled aboard the largest watercraft which has a capacity to carry up to 400 passengers. Thus, the majority of respondents were traveling in large groups to areas designated for more intense use.

Studies Undertaken Overseas

The United States has been active in addressing the issue of aircraft noise in its National Parks where an estimated 30 percent of all non-Alaskan National Parks experience overflight problems (US National Park Service 1994). Issues of aircraft noise in United States National Parks and at the Grand Canyon particularly, ultimately led to the enactment of the *US National Parks Overflights Act of 1987*. Aside from stipulating specific regulations for aircraft overflying certain US National Parks, the Act also stipulated that impact assessments and monitoring studies of aircraft flights over US National Forests and Parks be undertaken (US Forest Service 1992; US Federal Register Dec. 1996).

A recent development in the US, as a result of studies undertaken in accordance with the *Overflights Act 1987*, and scheduled to come into effect in early 1998, involves changes in the Federal Aviation Administration (FAA) legislation governing overflights over the Grand Canyon National Park. Changes include the capping of flight numbers, the further use of curfews and the modification of flight corridors (US Federal Register Dec. 1996; McCain 1997). FAA regulations also recently banned tour overflights in Rocky Mountain National Park where air tour operators were not yet in operation (US Federal Register May 1996). This is viewed as a proactive measure to prevent environmental problems before economic loss to air tour operators becomes an issue (Ernenwein et al. 1996).

Methods Used to Assess and Monitor Overflights

Several types of studies have been used to assess both actual and human perceived impacts of overflights and to monitor the effectiveness of legislation regulating overflights in US National Parks and Forests.

Studies have been based on assessing either spatial or temporal differences in aircraft sound exposure levels. Bowlby et al. (1986; 1990) undertook a spatial study in Grand Teton National Park, Wyoming, USA, aimed at determining whether or not a 55dBA Ldn contour, which had been generated in the vicinity of Jackson Hole airport, actually extended beyond the set boundary and into a defined noise sensitive area where the Ldn limit had been set at 45dBA. They monitored four sites (three of which were in the 45dBA area and one of which was in the 55dBA area) using automated type 1 sound meters, over four week long periods. They found that standards were generally complied with but that newer (B737/300) aircraft were less likely to exceed the standards than older and noisier (B737/200) aircraft. This highlights the importance of using quieter aircraft technology. Two monitoring studies based on assessing primarily temporal changes are discussed by the US National Parks Service (1994). Both studies aimed to determine whether or not legislative changes issued by the FAA in May 1988 and governing overflights over the Grand Canyon had been effective. Thus, comparative measurements based on the metrics Lmax and 'Percent of time audible' were taken prior to and after the legislative changes had been enacted (Fidell et al. 1994; US National Parks Service 1994).

Baseline and monitoring studies undertaken to date can be further summarised in the following categories:

- Indigenous and self noise sound studies;
- Aircraft sound studies;
- The combined use of secondary data sources with limited primary data to predict wide ranging impacts;
- The development of dose-response relationships and curves.

Indigenous and Self Noise Sound Studies.

A number of studies have been undertaken to establish and characterise indigenous sound levels in protected areas both for their own sake and to allow the impact of aircraft to be assessed.

Overall, indigenous sound levels were calculated to range for varying ecotypes from about 10dBA - 55dBA with the lowest measurements generally occurring during the night. Ambient indigenous sound levels in the order of 65dBA are postulated to be commonplace on windy days or near waterfalls or surf. Self-noise levels of hikers and horseback riders were shown to be more variable and an average of 13dBA higher than indigenous sounds. In order to calculate indigenous sound levels, artefacts of measurement including wind noise, and high level noise intrusions such as, animal noise, thunder and aircraft overflights were removed from the estimations (Fidell et al. 1990; Bowlby et al. 1990; US Forest Service 1992).

High spatial, temporal and spectral distributions of both indigenous and ambient sound levels were found to occur (Fidell et al. 1990; Bowlby et al. 1990; US Forest Service 1992). Indigenous sound levels were also found to have predictable statistical properties including a strong relationship between A-weighted sound levels and wind velocity. Furthermore, spatial, temporal and spectral patterns of correlation of sound levels can be used to quantify the degree to which anthropogenic noises intrude upon indigenous sound levels (Sneddon et al. 1994).

Aircraft Sound Studies

Aircraft sound studies have aimed to determine the acoustic profiles of both protected areas experiencing overflights and of various types of aircraft. Peak aircraft decibel levels recorded for all studies ranged from 47 to 107dBA. The majority of peaks being in the mid to lower section of this range. For example, Tabachnick et al. (1994) collected about 2 hours of overflight sound data in each of twelve wildernesses, and found that seven of ten sites recorded maximum peaks of 70dBA and below with estimated average peak levels ranging from 53dBA - 66dBA. Bowlby et al. (1990)

undertook a more extensive study over four week long periods. The data they recorded included aircraft takeoffs and landings. For one season at one site, they found that general aviation aircraft had a mean sound exposure level of 75dBA. Fidell et al. (1992) studied overflights in three wildernesses. Maximum aircraft noise levels recorded were in excess of 100dBA with an onset rate of 70dBA/s. Low flying military jets and helicopters were found to cause the highest sound levels typically reaching peaks of 70 or 75dBA with durations above background being longer for helicopters (approximately 100 seconds). Propeller driven planes typically reached amplitudes of about 62dBA with durations above background levels in the range of 60 seconds. High altitude transport jets typically reached an amplitude of about 58dBA for durations above background sound levels of about 40 - 60 seconds. Some high altitude overflights had virtually no measurable impact.

Horonjeff et al. (1993) determined the acoustic profiles for sites in the Grand Canyon, Hawaii Volcanoes and Haleakala National Parks. At the Grand Canyon data was collected at 23 sites (for an average of either 4 or 15 hours) in both flight and flight-free (below 14,000 ft) zones. Based on the metric 'percent of time audible', the general range of aircraft sound exposure in the Grand Canyon National Park was found to be from 5 - 80 percent of the time.

One method of ascertaining the impact of aircraft on indigenous sound levels is by comparing 'total' (all sources) Ldn with either 'aircraft only' or 'indigenous only' Ldn. If the difference between 'total' and 'aircraft only' Ldn is small (less than 3dB), aircraft are concluded to have been the dominate sound source. However if the difference is large (10dB or greater), aircraft are concluded to have had negligible effect on the total Ldn (Bowlby et al. 1990). Conversely the reverse is true if the comparison is between 'total' and 'indigenous only' Ldn (US Forest Service 1992). 'Total' Ldn can be relatively easily measured using an automated sound meter to record Leq values over a chosen period, such as 1 hour, which can then be computed into day (07:00 - 20:00), night (20:00 - 07:00) and 'total' Ldn values (Bowlby et al. 1990; US Forest Service 1992). 'Indigenous only' Ldn can be computed from short term Leq measurements (US Forest Service 1992). 'Aircraft only' Ldn values can be established by non-automated short term Leq recordings (US Forest Service 1992) or automated recordings (Bowlby et al. 1990). Bowlby et al. (1990) made automated 'aircraft only' Ldn measurements using a sound level threshold trigger to initiate recording. When compared with logs of aircraft activity, non-aircraft events (such as animal activity) were factored out of the 'aircraft only' Ldn calculation.

Sound level recordings have been related to aircraft types and movements (e.g. flight paths and directions of takeoff) allowing determination of the best types of movement and aircraft for preserving the natural quiet (Bowlby et al. 1986; Bowlby et al. 1990).

The Use of Secondary Data Sources

Secondary data sources have been used in conjunction with primary data to allow predictive modelling of the extent and impacts of aircraft overflights in protected areas. Tabachnick et al. (1992) developed a database (based on types and numbers of overflights), on behalf of the US Forest and National Parks Services, which was used to estimate overflight exposure for wildernesses where direct sound measurements weren't made. Noise exposure prediction equations and sound recordings made in similar wildernesses to those in question were used to compute the estimates. The database was then used to select sites with a range of visitor use and aircraft exposure conditions for social impact assessment. However, accurate determinations of aircraft activity and sound impacts over National Parks and Forest Service Wildernesses based on secondary data was concluded to be extremely difficult to achieve (US National Parks Service 1994).

The US National Parks Service (1994) also discuss an overflight decision support system (NODSS) which was developed to allow computerised acoustic modelling of sound levels over large areas. In the case of the Grand Canyon, NODSS was used to model future projections of the restoration of natural quiet under different management strategies. Information about types, numbers and altitude of aircraft, their flight routes and the topography of the region in question is used to compute sound levels over parks. Several sound metrics are able to be calculated including the time period that aircraft sound levels are above a specified threshold, Lmax and Leq values.

Dose-Response Relationships

Dose-response relationships describe the association between dose (aircraft exposure) and response (visitor impact). Once defined they can be used to produce dose-response curves, which can then be used to predict response by measuring or predicting dose (US National Parks Service 1994).

Dose response curves have been developed for several National Parks using the metrics: Ldn; Lmax; visit duration; visitor self reports of the numbers of aircraft noticed; Leq; and percent of time audible. Metrics were measured in conjunction with on site interviews at sites of varying levels and types of overflight exposure, visitor density and ecotypes. The metric found to be the best correlated with visitor response to aircraft sound was 'percent of time audible'. However, for predictive purposes, Leq is considered valuable, particularly if used in conjunction with the metric 'percent of time audible' (US Forest Service 1992; Fidell et al. 1992; Anderson et al. 1993; Tabachnick et al. 1994; US National Parks Service 1994). Conversely work by Bjorkman et al. (1992) undertaken in Sweden in the vicinity of two urban airports concluded that the annoyance reaction is better related to the number of aircraft and Lmax than to Leq measurements.

Dose response studies undertaken in National Parks in the USA showed sensitivity to aircraft sound to be site and setting specific. It was concluded that with careful use, dose-response curves can predict where visitors are likely to be significantly impacted by aircraft sound. Once sites of concern are identified (based on the frequency of overflights, human visitation rates and the recreation opportunity intended), sound data can be collected and then compared with an appropriate dose-response curve for the site. (US National Parks Service 1994).

Constraints of Overseas Studies

Limitations and problems encountered by the studies reported here include:

- The sound monitoring studies undertaken by and on behalf of the US National Parks and Forest Services only recorded overflights. They did not record aircraft landing and taking off close to parks and wilderness areas. This may have resulted in an underestimation of impact for parks and wildernesses with adjacent airfields.

- In some cases aircraft peaks could not be obtained due to high ambient and low aircraft sound levels.
- In cases where an automated sound meter was programmed to record sound levels at a defined decibel trigger, aircraft may have been audible but not loud enough to trigger a recording. This would result in lower than actual 'aircraft only' Ldn results.
- Some automated 'aircraft' recordings could not be explained and may have been due to animals rather than aircraft.
- A great deal of wind noise was recorded under extreme weather conditions despite the use of windshields.
- Ldn calculations (where 10dB is added to night time dB levels) gave inaccurate results when daytime dB levels were not significantly higher than night time dB levels.

  (Bowlby et al. 1990; US Forest Service 1992; US National Parks Service 1994).

Findings of Overseas Studies

Conclusions drawn by the studies discussed and relevant to this study are summarised as follows:

- The maximum dBA sound pressure level recorded from the single loudest (acoustic) overflight, controls the daily integrated noise exposure of many wildernesses.
- Aircraft overflights were audible even when their A-weighted sound pressure levels were comparable to the A-weighted level of indigenous sounds.
- Few people were significantly impacted by overflights. However, annoyance due to aircraft was more strongly related to noise than to visibility or condensation trails, and natural quiet was concluded to have significant value to visitors.
- Dose-response studies showed a definite increase in response with an increase in dose.
- Implications were that: by decreasing the sound exposure, impacts decrease; some areas/settings are more important to protect from aircraft overflights than others; and that the maximal acceptable percentage/number of people impacted at a site can be set. (US Forest Service 1992; US National Parks Service 1994).

Recommendations for future management of protected areas experiencing aircraft overflight problems included:

- Expansions of flight free areas over parks, capping flight numbers and using curfews;
- Exploiting natural attenuation and therefore minimising altitudes where terrain can be used as an acoustic shield (although this increases sound levels directly below the flight path) while increasing altitude where terrain can't be used as a shield;
- Encouraging noise reductions at the source either by using quieter aircraft or retrofitting existing aircraft;
- The use of greater payloads and noise budgets;
- The improvement of regulations and the use of voluntary agreements between park authorities and tour operators; and
- Acoustic monitoring programs with defined triggers and action plans.

The point was made that solutions should be sought at the local level due to the unique nature of different situations (US National Parks Service 1994).

RESEARCH METHODS

Study Site

The study site is Whitehaven Beach, situated on the east coast of Whitsunday Island, Queensland, Australia. Whitehaven Beach is approximately six kilometres long and adjoins Hill Inlet to the north west and Solway Passage to the south east. The beach consists of white silica sand and is backed by two sand dune systems, the younger of which forms the landward boundary of the beach. Elevation reaches 20 meters above sea level at approximately 200 meters inland from the beach. Elevation climbs rapidly to 60 meters at the northern end of the beach and to 97 meters at the southern limit of the beach. Figure 3.1 shows Whitehaven Beach within the Whitsunday Islands. Figure 3.2 is a photograph taken from the air at about 1000 feet looking along Whitehaven Beach toward Hill Inlet.

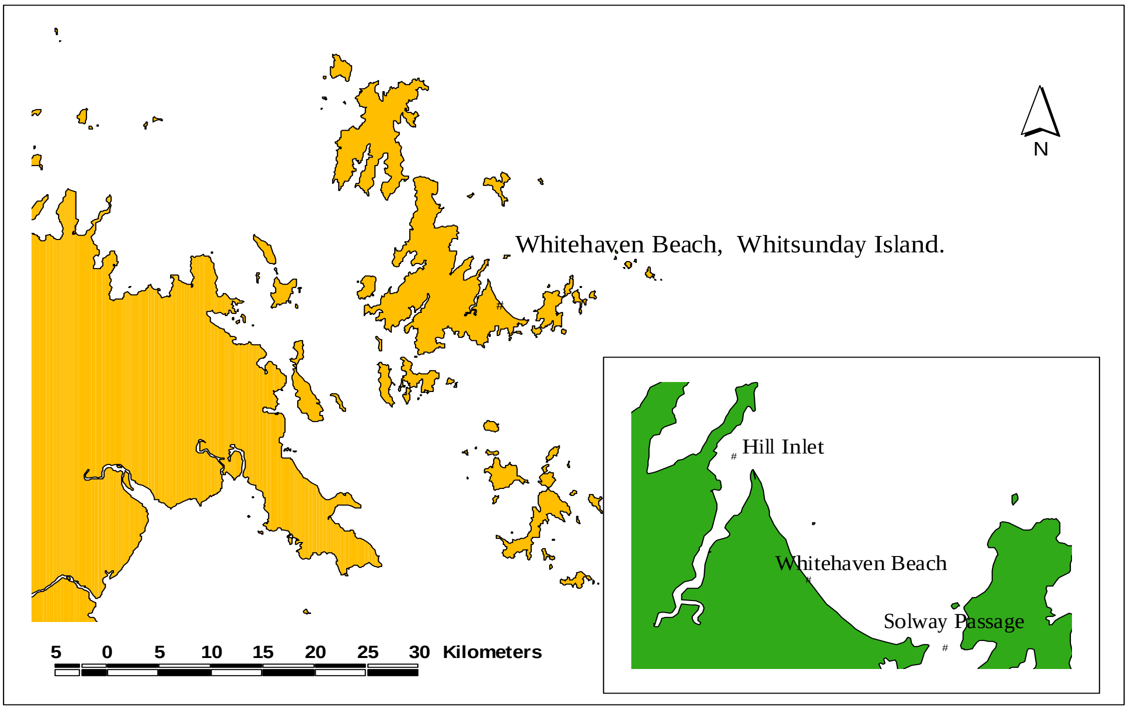

Figure 3.1. Whitsunday Islands and adjoining mainland, North Queensland, Australia. The insert shows Whitehaven Beach *(Source: GBRMPA)*.

Figure 3.2. Photograph of Whitehaven Beach looking NNW toward Hill Inlet.

The Whitsunday Islands are divided into five recreation opportunity settings which are classified; developed (also referred to as setting 1), high use (setting 2), moderate use (setting 3), natural (setting 4) and protected (setting 5). Setting 1 receives the most intensive use, motorised water sports are designated to be conducted only in setting 1. Along Whitehaven Beach are settings 2, 3, 4 and 5, graduating from a high use setting at the southern end of the beach to a protected setting at the northern end of the beach. Each setting along the beach is between approximately one and two kilometres wide. Setting 2 is described as a natural setting, experiencing high levels of visitation by larger vessels and aircraft (a vessel size of up to 35 meters with an unlimited passenger load is permitted). Appropriate facilities (e.g. pontoons, moorings and markers) are provided. Toilets and picnic tables are also provided behind the beach in setting 2 on Whitehaven Beach. Setting 3 is described as a natural setting expected to receive moderate levels of visitation with occasional visits by larger vessels and aircraft (a vessel size of up to 35 meters with a passenger load of up to 40 people is permitted). Setting 4 is described as a natural setting with low levels of visitation. Areas classified as setting 4 are expected to be generally free from facilities and larger vessels and aircraft (a vessel size of up to 20 meters with a passenger load of up to 15 people is permitted). Setting 5 is described as a protected natural setting. Areas classified as setting 5 are managed according to individual site plans. Hill Inlet is classified as a setting 5 area due to its conservation (mangroves, seabird nesting), scenic (silica sand inlet and delta which has become an icon) and cultural values. Aircraft are not to access Hill Inlet (setting 5), however watercraft up to 12 meters in length are permitted. Although only the Hill Inlet end of Whitehaven Beach is classed as setting 5, the entire beach is described as a sensitive site. Individual management strategies for areas classified as sensitive sites are under development (GBRMPA 1998). Figure 3.3 depicts the settings along Whitehaven Beach and Bay.

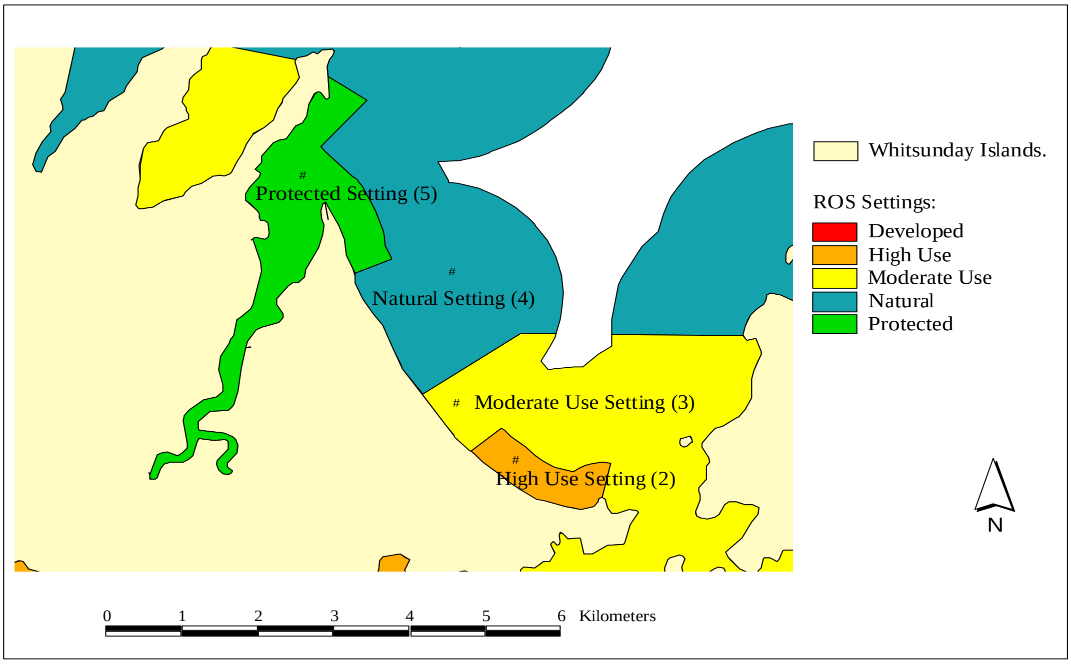

Figure 3.3. The recreation opportunity spectrum settings along Whitehaven Beach. *(Source: GBRMPA)*

Whitehaven Beach and the Whitsunday Islands generally have also been divided into five types of aircraft landing zones. The landing zones at Whitehaven Beach and its immediate surrounds are depicted in figure 3.4. The regular multiple landing area extends along the beach front from the boarder of settings 2 and 3 to the middle of setting 4. The seasonal multiple landing area encompasses the entire beach front of settings 3 and 4. Settings 2 and 5 along Whitehaven Beach are zoned as permanent closure areas. A seasonal multiple use landing area also occurs on the northern side of Hill Inlet (setting 5). Aircraft are restricted to accessing the area between the hours of 07:00 and 17:00 (McLeod, *pers. comm.*, 1998).

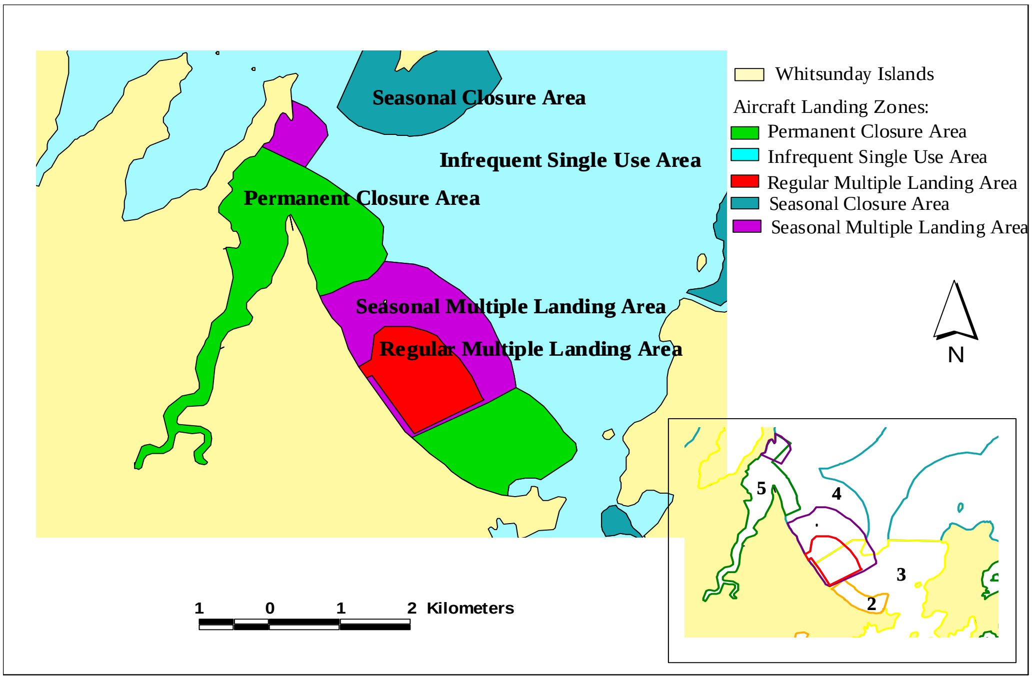

Figure 3.4. Aircraft landing zones along Whitehaven Beach. The insert shows the landing zones relative to the ROS settings *(Source: GBRMPA)*.

Survey Design

Sites of Data Collection

For the purposes of this study, sites for data collection were placed in the central area of each setting along Whitehaven Beach. A data collection site in the centre of each setting was necessary in order to ensure that results obtained for each setting were representative of the core of the setting. A Magellan GPS 3000 XL Satellite Receiver (accurate to within 100 metres horizontally and 150 metres vertically with greater inaccuracy about 5% of the time due to errors induced by selective availability) was used to locate universal transverse mercantor co-ordinates central to each setting. Stakes were driven into the sand at each site and maintained there throughout data collection trips 1 and 2. Sites were photographed to ensure later identification in the event of the stakes being removed. Stakes were placed at the top of the beach at the base of the sand dune at each data collection site. Figure 3.5 depicts the location of data collection sites relative to each setting. Figures 3.6 - 3.9 are photographs of each data collection site.

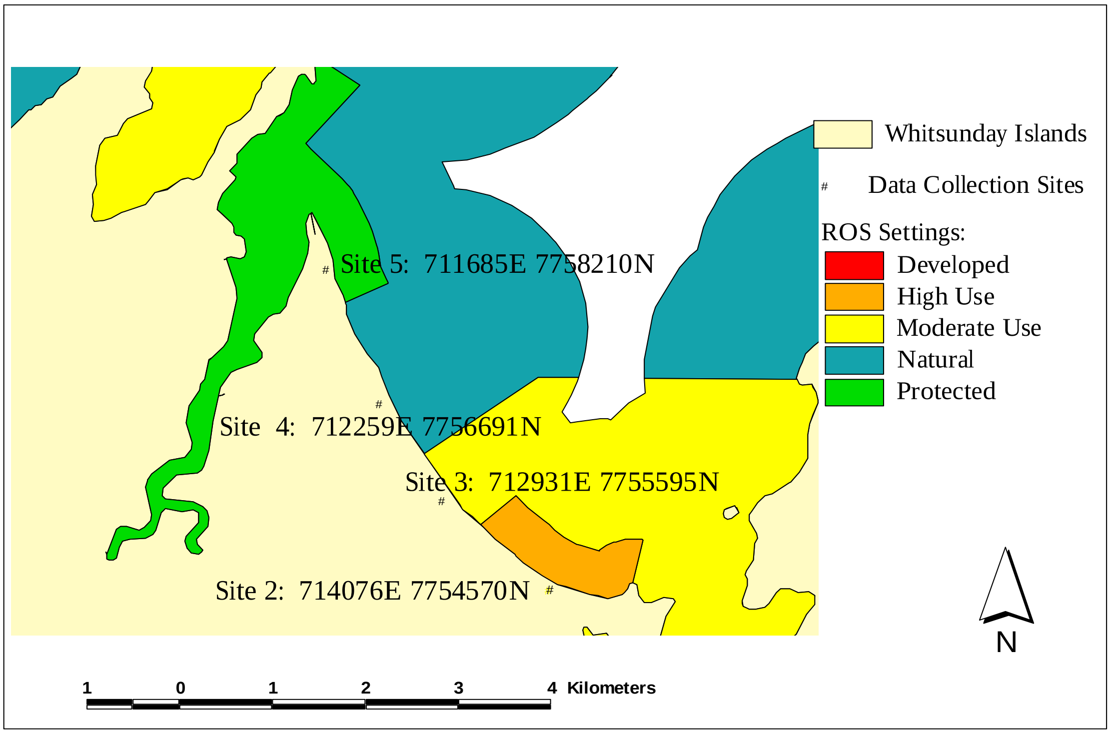

Figure 3.5. Data Collection sites relative to ROS settings, Whitehaven Beach. *(Source: GBRMPA)*

Figure 3.6. Study Site 2, Setting 2.

Figure 3.7. Study Site 3, Setting 3.

Figure 3.8. Study Site 4, Setting 4.

Figure 3.9. Study Site 5, Setting 5.

Data Collection Periods

Most of the data was collected during two four-day periods, two weeks apart, from the 10th - 13th of October (trip 1, data collection days 1 - 4) and from the 24th - 27th of October 1998 (trip 2, data collection days 5 - 8). Further data was collected with the aid of Hamilton Aviation on the 7th and 8th of December, 1998 (trip 3, data collection days 9 & 10).

During trips 1 and 2, data was collected at the four sites described in the previous section. Data was collected from the time of arrival at each site in the morning until 10:00, from 10:30 - 13:30 and from 14:00 - 17:00. The aim was to start collecting data at all sites from 08:00 however this was not possible on all days. During trip 3, data was collected from where Hamilton Aviation was operating for the day. Data was collected from the time of arrival until the time of departure. On both days this was from about 10:00 - 16:00.

Survey Methods

Variables Measured

The variables measured during the data collection trips, their periods of measurement, and the techniques used are outlined in tables 3.1 to 3.7. Please refer to the following descriptions when interpreting these tables.

Table 3.2 - Lp Sound recordings at 10s intervals: Recordings were started on a 00, 10, 20, 30, 40 or 50 second mark as close as possible to the start of the sound event (aircraft/watercraft) and at each ten second interval thereafter to allow readings taken at each site to be correlated temporally.

Table 3.2 - Distance between the recorder and an aircraft takeoff, landing or flyover: During trips 1 and 2, within the regular landing zone, red and white ranging poles were set up at 200m intervals in order to allow a rough judgement to be made of the distance between a recording site and a landing or take off. During trip 3 range finder binoculars were used to judge distance. In this case, distance measurements were taken at the same time as sound level recordings whenever the aircraft was within range.

Table 3.2 - Type of event: On trips 1 and 2, event types were categorized as follows: seaplane flyover landing, seaplane takeoff flyover, seaplane flyover only, helicopter flyover landing, helicopter takeoff flyover, helicopter flyover only, seaplane taxi only, high altitude jet flyover and other light aircraft flyover. Categories used on trip 3 were seaplane flyover, seaplane landing, seaplane takeoff, seaplane taxi (before takeoff / after landing), helicopter flyover, helicopter landing and helicopter takeoff.

Table 3.2 - Techcessories analogue sound level meters: Techcessories analogue sound level meters (decibel meters catalogue number: 33-2050). Featuring A and C weighting networks and fast (indicates peak sound levels) and slow (indicates average value sound levels) response settings but not meeting national or international requirements for types 0, 1, 2, or 3 sound level meters. All were new and correctly calibrated at the beginning of the data collection periods. These sound meters were unable to read below 50 decibels.

Table 3.2 - Integrated Type 2 Rion sound level meter: A Rion NA-29 octave band analyser and a UC-52 microphone, both conforming to the IEC standard for type 2 sound level meters. However, both were long overdue for a professional calibration check. When checked at Workplace Health and Safety the meter was reading approximately 1.8dBA lower than it should have been. This sound meter was used only to provide a comparison with the analogue sound meters. Results from the integrated meter were not used in the main analysis.

Table 3.2 - Range finder binoculars: 'Yardage Pro 800' Range finder binoculars with a maximum range of 800 yards / meters under most circumstances (dependant on the reflectivity of the target) and an accuracy of + / - 1 yard / meter.

Table 3.3 – Lmax of ‘significant’ events: Watercraft events were subjectively selected for recording based on whether or not observers judged them to have a significantly audible noise level (detectable above background decibel readings). Aircraft events occurring at the same time always took precedence.

Tables 3.4 - 3.7 – Note that boundaries between settings 2 & 3 and 4 & 5 were indicated by ranging poles which also marked the outer boundaries of the seasonal landing zone. The boundary between setting 3 & 4 was estimated by judging, with the aid of binoculars, the half way mark between data collection sites 3 and 4. It was assumed for the purposes of this study that the sites at which the variables, wind, temperature and humidity were collected are representative of all four data collection sites along the beach. Wind, temperature and humidity data were collected as recommended by Australian Standard 1055 (Standards Australia 1997).

Table 3.1. Background Sound Level Data Collection.

Sampling Period	Variable	Equipment Used	Sites of Data Collection
Trip 1. Trip 2. Trip 3.	• Average dBA / minute. Calculated from max and min decibel levels recorded over every 10s in a minute at 15 minute intervals (unless an aircraft event was taking place). ♦ Leq (5 or 10s).	• Four Techcessories analogue sound level meters. • Synchronised Digital/analogue watches. ♦ Integrated type 2 Rion sound level meter.	• Sites 2, 3, 4, 5 during trips 1 and 2 plus a site close to Hamilton Aviation's operation during trip 3. ♦ Site 5 during trip 1, site 3 during trip 2 and a site close to Hamilton Aviation's operation, trip 3.

Table 3.2. Aircraft Activity and Sound Level Data Collection

Sampling Period	Variable	Equipment Used	Sites of Data Collection
Trip 1. Trip 2. Trip 3.	• Lmax of each event. • Lp Sound recordings at 10s intervals. • Duration of sound events above background sound levels. • Frequency of Occurrence of events. ♦ Leq (5s), Lmax (5s). ❖ Distance between the recorder and an aircraft takeoff, landing or flyover. ❖ Type of event.	• Techcessories analogue sound level meters. • Synchronised Digital/analogue watches. ♦ Integrated type 2 Rion sound level meter. ❖ Ranging Poles. ❖ Tape measure. ❖ Range finder binoculars. ❖ Standard binoculars.	• Sites 2, 3, 4, 5 ❖ during trips 1 and 2 plus a site close to Hamilton Aviation's operation during trip 3. ♦ Site 5 during trip 1, site 3 during trip 2 and a site close to Hamilton Aviation's operation during trip 3.

Table 3.3. Watercraft Activity and Sound Level Data Collection

Sampling Period	Variable	Equipment Used	Sites of Data Collection
Trip 1. Trip 2.	• Lmax of 'significant' events. ♦ Leq(5 s), Lmax(5 s). ❖ Numbers of watercraft passing through settings. ❖ Numbers of events recorded.	• Techcessories analogue sound level meters. • Synchronised Digital / analogue watches. ♦ Integrated type 2 Rion sound level meter.	Sites 2, 3, 4 and 5.

Table 3.4. Levels of Human Use Data Collection

Sampling Period	Variable	Equipment Used	Sites of Data Collection
Trip 2.	• Numbers of people present on the beach within each setting at 10:30, 14:00 and 17:00.	• Standard binoculars. • Watch.	Sites 2, 3, 4 and 5.

Table 3.5. Wind Speed and Direction Data Collection.

Sampling Period	Variable	Equipment Used	Sites of Data Collection
Trip 1. Trip 2. Trip 3.	• Average wind speed during sound recordings (data collected as much as possible whenever a sound recording took place). ❖ Wind Direction.	• Aniometer. • Stopwatch. • Watch. ❖ Wind Direction Indicator. ❖ Compass.	Site 4.

Table 3.6. Temperature Data Collection

Sampling Period	Variable	Equipment Used	Sites of Data Collection
Trip 1. Trip 2.	• Atmospheric temperature (collected at 30 min. intervals).	• Thermometer. • Watch.	Site 2.

Table 3.7. Humidity Data Collection.

Sampling Period	Variable	Equipment Used	Sites of Data Collection
Trip 2.	• Atmospheric humidity (collected at 30 min. intervals).	• Wet and Dry Thermometer. • Watch.	• Site 2.

Data Collection

Sound level data was collected from two paces in front of the marking stake at each site. The main sound data was collected using analogue sound level meters. These were numbered and each site always used the same meter. Analogue sound meters were held horizontal at breast height, on the right hand side with the microphones facing directly to sea at all times. Recordings were made by pairs of volunteers, one person read the analogue sound meter while the other indicated when readings were due and recorded the results. Silence was maintained throughout the process other than when the person reading the meter stated the result. The volunteer noting the results stood to the left of the person with the sound meter to reduce interference with sound waves. Analogue sound meters were set to A-weighted network and fast response settings for all sound level recordings. Details of sound sources were also recorded.

Figure 3.10. Sound level data collection with the analogue sound level meters.

During aircraft and watercraft recordings, symbols were used to detail movement of the sound source relative to the observers, in order to aid later interpretation of the data (refer to appendix 1 for a list of the symbols used). Samples of the survey proforma used in the field to record background, aircraft and watercraft sound and activity levels, plus those used to record environmental conditions are in appendix 2.

Comparative automated sound recordings were made for all sound sources using a type 2 integrated sound level meter. This provided a means of assessing the accuracy of the analogue sound meters. As it was not possible to take continuous measurements over a day with the integrated meter, only selected events were recorded. Background recordings made with the integrated meter were spread throughout the day at regular intervals. They were also made over ten minute intervals during break periods and at the end of the day. The integrated meter was also set to ‘A’ weighting and fast response settings for all sound recordings. Comparisons of recordings made with the two types of sound meter are presented in appendix 3.

The major difference between the methods of sound level recordings made on trips 1, 2 and 3 was that wind screens were used on the analogue sound meters on trips 2 and 3 but not on trip 1. This was because the analogue sound meters did not come with windscreens while the researcher had also been advised that windscreens would not be necessary. A windscreen was always used with the type 2 integrated sound meter.

Methods of Analysis

Data was collated, analysed and presented using the spreadsheet programs Excel and SPSS, and the mapping program ArcView. Data collected during trips 1 and 2 was divided into seven hourly periods of each day for analysis. Periods chosen were as follows: 9:00 - 10:00 (1); 10:30 - 11:30 (2); 11:30 - 12:30 (3); 12:30 - 13:30 (4); 14:00 - 15:00 (5); 15:00 - 16:00 (6); 16:00 - 17:00 (7). On all days, data had started to be recorded at all sites by 9:00 am, thus data from 9:00 am onward was included in the analysis. Forty-five hours of data was available for analysis from the first two data collection trips and was used to analyse differences between sites (settings) and times of day. It was also used to establish average background sound levels. Data collected during trip 3 was used to quantify the relationship between distance and sound level and to provide further data on the relative sound impacts of different types of aircraft events. Approximately eleven and a half hours of data was available for analysis from trip 3.

Prior to fully analysing sound level data, correlation analysis between average daily wind speed and sound level data collected during trips 1 and 2 was undertaken. As windshields were used on trip 2 but not on trip 1, wind noise was expected to have had a greater influence on trip 1. Correlation analysis (appendix 4.1 and 4.2) established a positive correlation between wind speed and sound level variables for trip 1 (days 1 - 4) but not for trip 2 (days 5 - 8). Subsequently sound level data from days 1 and 2 was excluded from further sound level analyses. However, sound level data from days 3 and 4 was used in further sound level analysis as wind speed averages were lower on those days while average background sound levels were within the range of the results from days 5 - 8.

Temperature and humidity data were not analysed relative to other variables as little variation in temperature or humidity was recorded and the data collected was not considered sufficient for meaningful analysis. Nevertheless daily averages were calculated and are presented in appendix 4.3.

Background Sound Data

Ideally both a natural (background) and a 'nuisance' noise threshold would be established and used for comparison with aircraft sound levels. Comparison with a nuisance threshold would allow the impact of noise at Whitehaven Beach on humans to be assessed. However, a nuisance threshold cannot be established without undertaking concurrent social surveys at the study site. As this was beyond the scope of this study, aircraft sound levels were assessed relative to calculations of average background sound levels, established through the analysis of background sound level data collected on trips 1 and 2. Readings with anthropogenic influences (boats, people or aircraft) were excluded from analysis. Bird sounds were not excluded although they were observed to raise background sound levels by approximately 20dBA. Background sound levels were calculated in the following ways:

1. Average natural sound level at each site on each of days 1 - 8.
2. Average natural sound level at each site over days 3 - 8.
3. Average natural sound level for the entire study area over days 3 - 8.

An attempt was made to compare natural sound levels between times of day. However, due to variations in the size of data sets for individual time periods, this method of analysis was not pursued. A factorial analysis of variance was used to further compare differences in natural sound levels between sites and trips.

Aircraft Data

Of the data collected on trips 1 and 2, all aircraft events occurring in time periods 1 - 7 were analysed. Events, which overlapped with break periods, were included in the analysis. Aircraft events were analysed in terms of aircraft activity and aircraft sound.

Aircraft Activity

Analysis was based on 45 hours of data collected over days 1 - 8. Aircraft activity was investigated in terms of:

- numbers of aircraft events relative to sites and trips;
- types of aircraft events relative to sites;
- numbers and types of aircraft events relative to times of day;
- proportions of sites affected by the same aircraft visits.

All aircraft events recorded at data collection sites, regardless of whether or not they registered above background sound levels and whether or not the aircraft event passed through their setting, are regarded as having had an impact (or they wouldn't have been observed) and were therefore included in the analysis. Comparisons made were primarily qualitative. A factorial analysis of variance was used to further compare differences in activity between sites and trips.

Aircraft Sound

Analysis was based on 31 hours of data collected over days 3 - 8 unless otherwise stated. Aircraft sound levels are compared against either the 'average natural sound level over the entire study area' or against 'site specific average natural sound levels' (as discussed in the background sound data results). Aircraft sound is then described in terms of:

- the proportion of aircraft events which registered above average background sound at each site and over the entire study area (site specific analysis was based on 45 hours of data collected on days 1 - 8 and site specific average natural sound levels);
- maximum sound levels at each site, on each trip and over the entire study area;
- maximum sound levels relative to event types (analysed separately for data collected on days 3 - 8 and for data collected on days 9 and 10 (trip 3));
- maximum sound levels relative to distance from seaplane takeoffs (based on 11.5 hours of data collected on days 9 and 10);

- the duration of aircraft sound above background sound levels at each site and over the entire study area.

Comparisons made were primarily qualitative. A factorial analysis of variance was used to further compare differences in aircraft Lmax sound levels between sites and trips.

The duration of aircraft events above average natural sound level was estimated by counting up the number of readings for each event with values above the established overall average natural value (57dBA) and multiplying them by 10 seconds (the interval between recordings). When a single maximum sound level or duration was recorded for concurrent aircraft events, they were analysed as a single event and termed a 'cumulative event'. The number of cumulative events recorded at any site are noted and presented in the results along with events which were noted but which were not recorded.

Of the data collected on days 9 and 10 (trip 3), all seaplane events run by Hamilton Aviation and all helicopter events were analysed to further establish a relationship between event type and noise levels experienced on the beach. Maximum decibel levels recorded for seaplane takeoffs were also correlated with distance between the recorder and the sound source. Seaplane takeoffs were chosen for this analysis as they had been identified as causing the highest sound levels and also provided the largest database. Estimations of takeoff distances made using ranging poles during trips 1 and 2, were not used in the analysis due to the more accurate data collected during trip 3 using range finder binoculars.

Watercraft Data

The absolute maximum decibel level recorded for a single watercraft event, the average number of watercraft observed in a day, the total number of watercraft events recorded over all days, and the types of watercraft events occurring were all qualitatively compared between settings.

Human Use Data

The number of people in each setting, at 10:30, 14:00 and 17:00 was averaged over all days of data collection. Averages were then compared between settings both qualitatively and quantitatively using chi-squared analysis.

RESULTS

This chapter presents an analysis of aircraft sound and activity levels at sites in the recreation opportunity spectrum settings along Whitehaven Beach. The analysis is presented under the following headings, aircraft activity; aircraft sound; other anthropogenic influences; summary of results. Data is analysed relative to the whole study area and within the context of settings. Where appropriate it is also analysed in relation to time of day.

Aircraft Activity

In this section aircraft activity is investigated in terms of:

- numbers and types of aircraft events relative to sites;
- numbers and types of aircraft events relative to times of day;
- proportions of sites affected by the same aircraft visits.

Analysis is based on 45 hours of data, collected over days 1 - 8.

Numbers and Types of Aircraft Events Relative to Sites

Figure 4.1 shows that overall site 2, situated in the high use setting, received the lowest number of aircraft visits followed by site 5 (protected setting). Sites 4 (natural setting) and 3 (moderate use setting) received the highest number of visits. Figure 4.2 shows this trend to be consistent between trips. Hourly averages and standard errors in figure 4.2 are calculated using hourly rates per day at each site as replicates. However, rates from days 4 and 8 were excluded from the calculation, as they are likely to bias the result due to being based on smaller sample sizes collected only in the morning (the busiest time of day).

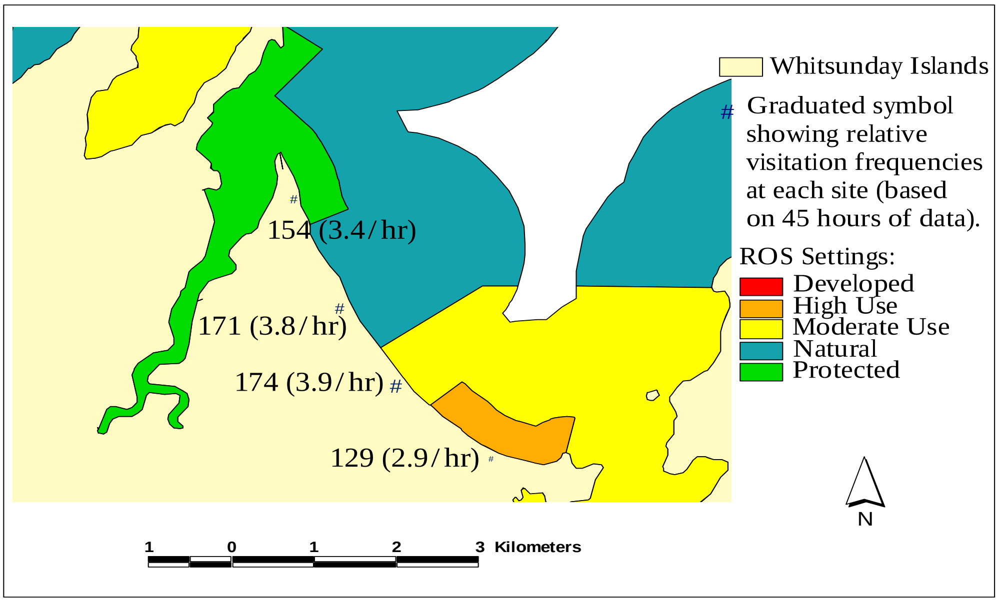

Figure 4.1. Total number of aircraft events relative to data collection site.

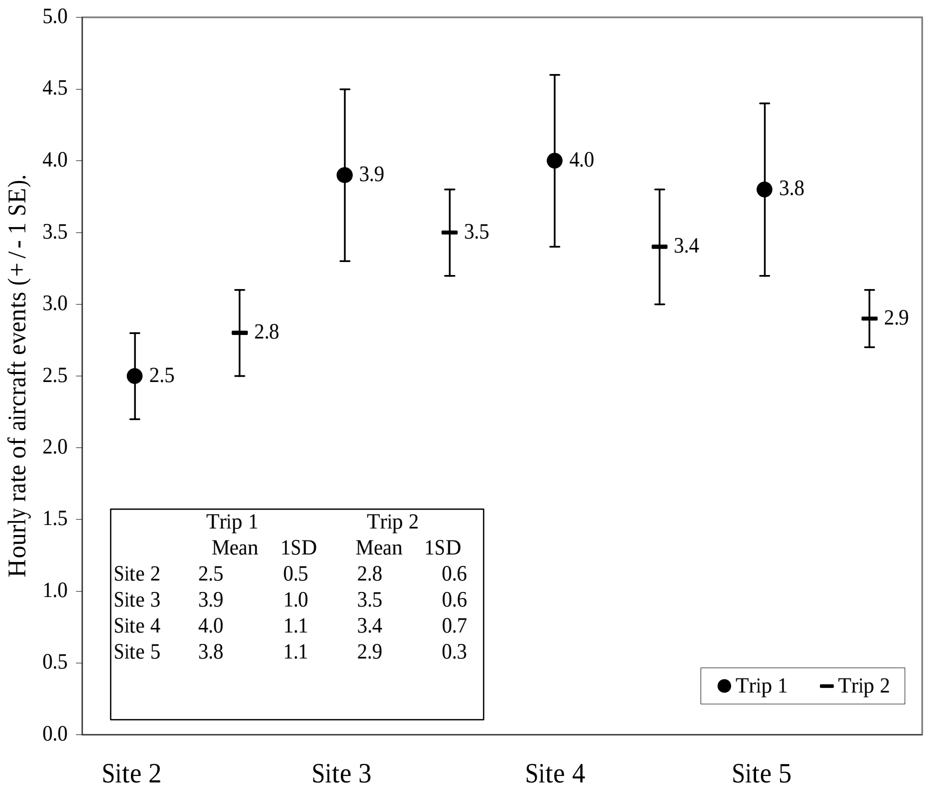

Figure 4.2. Hourly rate of aircraft events at each site on each trip +/- 1 SE.

Figure 4.3 shows that the most common type of aircraft observed at each site were seaplanes, followed by helicopters, other light aircraft and high altitude jets. Military jets are also reported to fly over Whitehaven Bay area at low altitudes but were not observed during the period of this study. High altitude jet flyovers are probably under represented as in many cases they were not noticed or were noticed but not recorded due to their low sound levels. The highest within site proportion of helicopter events (32%) occurred at site 5 and decreased down the beach to site 2, which experienced the lowest proportion (17%). Seaplane events show the opposite trend, site 2 experiencing the highest within site proportion (73%) and site 5 the lowest (60%). Discrepancies between the number of landings and the number of takeoffs of both seaplanes and helicopters are explained by the fact that a high proportion of takeoffs as compared to landings were noted to have occurred during break periods and therefore were not accounted for in the analysis. A few takeoffs may also have occurred after data collection was completed for the day. This is particularly true for days 4 and 8 when data was only collected in the morning.

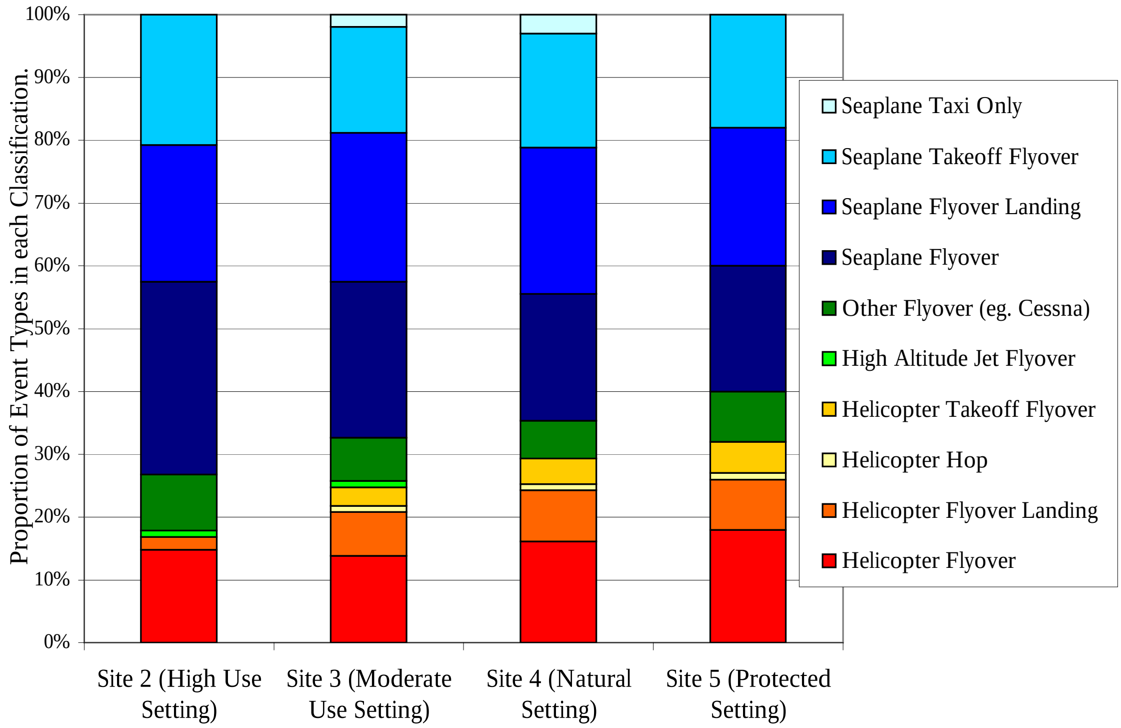

Figure 4.3. Proportion of event types experienced at each site.

Numbers and Types of Aircraft Events Relative to Times of Day

The number of aircraft events relative to site and time of day is depicted in figure 4.4. The busier period of the day at all sites was in the morning peaking between 11:30 and 12:30 with numbers of flights ranging from 4.7/hour to 6.2/hour. The least busy time of day was between 16:00 and 17:00 when numbers of flights ranged from 1.0/hour to 1.5/hour. Observations and recordings suggest that overflights start at 07:00 and that between 08:00 and 09:00 the number of aircraft events occurring is similar to the number occurring between 09:00 and 10:00. Few overflights were observed after 17:00.

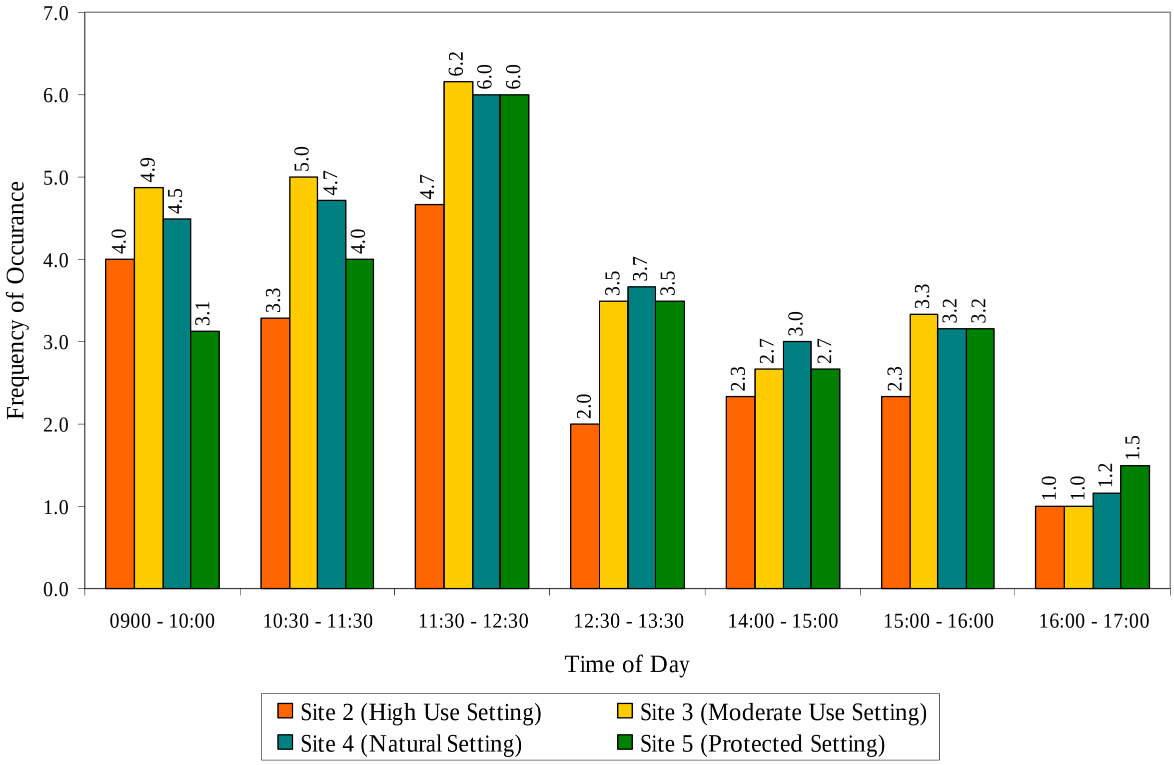

Figure 4.4. Average hourly number of aircraft events at each site.

How event types varied with time of day is depicted in figure 4.5. Seaplane events were most common in the morning. All other event types do not show a trend of activity relative to time of day.

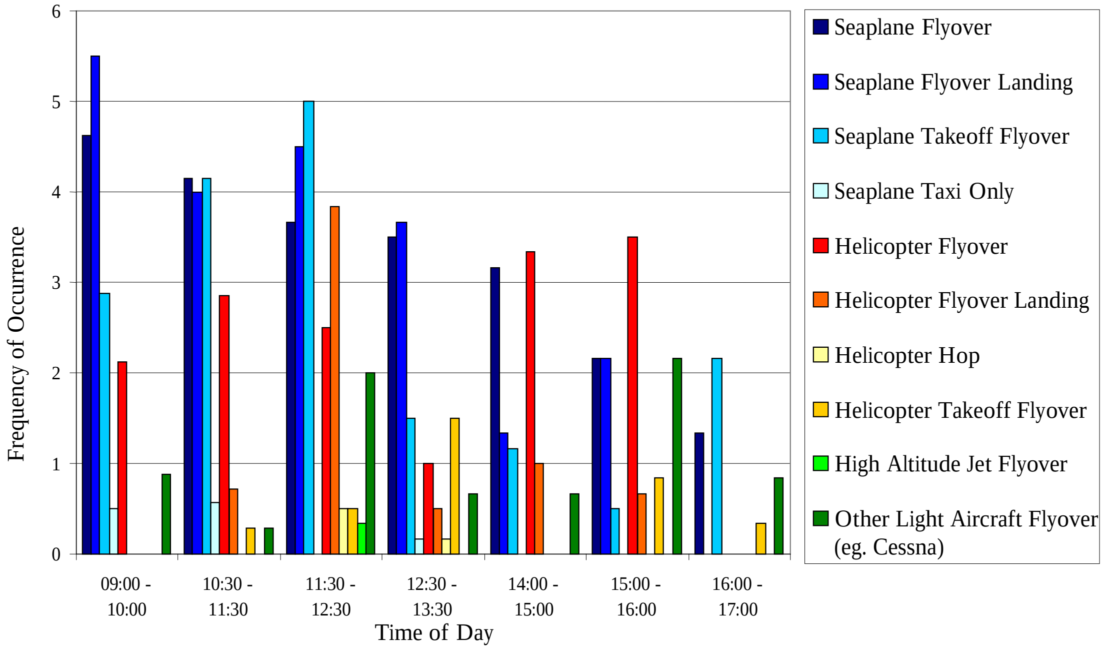

Figure 4.5. Average hourly number of different types of aircraft events.

Proportions of Sites Affected by the Same Aircraft Visits

Figure 4.6 shows that 71% of all aircraft visits to Whitehaven Bay affected 3 or 4 sites. Time series graphs for selected aircraft visits are given in appendix 5 based on concurrent recordings made at sites 2, 3, 4 and 5.

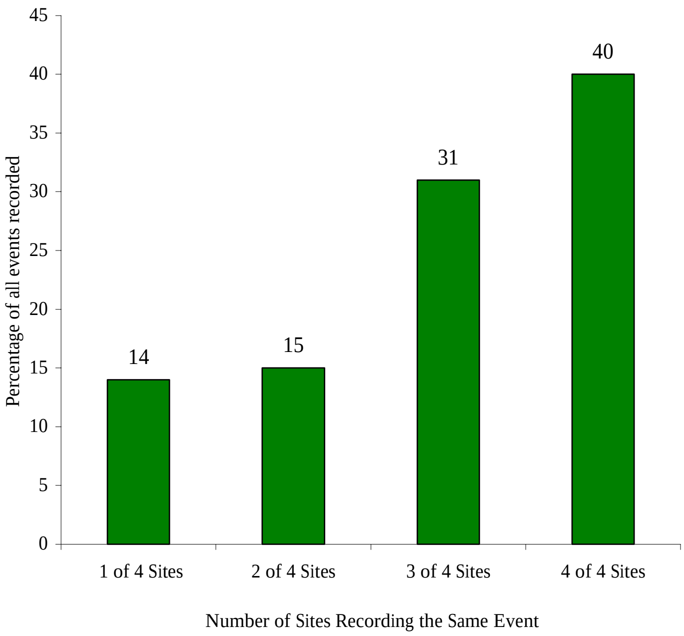

Figure 4.6. Proportion of aircraft events affecting 1, 2, 3 or 4 sites.

AIRCRAFT SOUND

Natural Sound Levels

Tables 4.1 and 4.2 present background sound level data collected using two types of instrumentation. Data in table 4.1 was collected at all 4 sites on each of days 1 - 8, using analogue sound level meters. Data in table 4.2 was collected at either site 3 or 5 on each of days 1 - 8, using a Rion type 2 integrated sound level meter. Data for days 1 & 2 (presented in italics) was not used for further analysis due to the outcome of the correlation analysis between wind speed and average daily sound levels as discussed in the methods section. Note that analogue sound level meters were incapable of reading below 50dB. Means are based on data collected over a day. The size of a days data set varied, consisting of seven hours of data collection on days 1 - 3 and days 5 - 7, two hours of data on day 4 and one hour of data on day 8. However, excluding data from days 4 and 8 gives the same trend and similar results.

Table 4.1. Average background sound levels.

Day	Site 2	Site 3	Site 4	Site 5	Daily Average	Std. Dev.	Ave Wind Speed And Direction
1	*73*	*68*	*63.8 (64)*	*61.1 (61)*	*66.4*	*5.1*	4.4 m / s NNW
2	*57.3 (57)*	*63.5 (64)*	*63.7 (64)*	*61*	*61.4*	*3.0*	4.3 m / s ESE
3	54.1 (54)	58.7 (59)	55.7 (56)	55.4 (55)	56.0	2.0	2.6 m / s ENE
4	56.5 (57)	58.5 (59)	57.5 (58)	53	56.4	2.4	3.1 m / s N
5	56.5 (57)	58.1 (58)	59.3 (59)	57.8 (58)	57.9	1.1	4.0 m / s SE
6	59	56.5 (57)	57.9 (58)	54.7 (55)	57.0	1.9	1.7 m / s N
7	58.8 (59)	57.2 (57)	57.6 (58)	54.3 (54)	57.0	1.9	3.9 m / s NW
8	57.6 (58)	58.4 (58)	56.3 (56)	51.4 (51)	55.9	3.1	3.0 m / s N
Range (days 3 - 8)	54 - 59	57 - 59	56 - 59	51 - 58			
Mean (days 3 - 8)	**57.1**	**57.9**	**57.4**	**54.4**			
Std. Deviation	1.8	0.9	1.3	2.2			
Mean (days 3, 5 - 7)	57.1	57.6	57.6	55.6			

Overall Mean & SD for all sites over days 1 - 8.	Mean = 58.5	1 SD = 3.6
Overall Mean & SD for all sites over days 3 - 8.	Mean = **56.7 (57dBA)**	1 SD = 0.8

Table 4.2. Comparative background sound level data. Based on data collected with the type 2 Rion integrated sound level meter. A more sensitive meter than the analogue meters and capable of reading below 50dB.

Day	**Site 3**		**Site 5**	
	Average	**Minimum**	**Average**	**Minimum**
1			55.0	47.0
2			53.6	51.0
3			48.2	39.5
4			45.4	41.0
5	56.1	50.7		
6	54.0	50.1		
7	54.4	46.8		
8	No data collected due to poor weather conditions.			
Average and minimum at each site				
	54.8	**46.8**	**50.6**	**39.5**
Overall average and minimum				
	52.4	**39.5**		

It is apparent from table 4.1 that natural sound levels at site 5 are lower than at all other sites. Natural sound levels at sites 2, 3 and 4 are similar. Results presented in table 4.2 support this conclusion and also suggest that background averages calculated from data collected with the analogue sound meters are higher than actual. The most obvious reason for this is in the fact that the analogue meters were unable to read below 50dB resulting in elevated averages whenever sound levels were below 50dB. Despite this, comparisons between anthropogenic and natural sound level data are based on background measurements made with the analogue sound meters (table 4.1) as the analogue data constitutes a more comprehensive database.

Aircraft Sound Levels

In this section, data is presented both in the context of the whole study area and also relative to the sites. Aircraft sound levels are compared against either the overall average background sound level (57dBA) or against site specific average background sound levels. Aircraft sound is then described in terms of:

- the proportion of aircraft events which registered above average background sound;
- maximum sound levels recorded, their distributions and how they relate to event types;
- the duration of aircraft sound above background sound levels.

Proportion of Aircraft Events Registering Above Background Sound

Table 4.3 is based on data collected over days 1 - 8 and shows that of the aircraft recorded at sites 3, 4 and 5, approximately 95% emitted sound levels registering above the average daily natural sound level at the site. In the case of site 2, the figure was 85%. Overall 88% of aircraft recorded at all sites on days 3 - 8 registered above the overall average natural sound level of 57dBA.

Table 4.3. Proportions of aircraft events registering above the average background sound level recorded at each site on each day. Calculated based on the corresponding background threshold level recorded at each site on each day.

Day	Site			
	2	**3**	**4**	**5**
1	85.7	100	87.5	93.8
2	90.5	93.3	88.2	87.5
3	88.2	100	92.6	91.3
4	64.3	87.5	100	100
5	100	95	100	94.1
6	86.7	100	92.9	100
7	66.7	82.6	95.2	94.1
8	100	100	100	100
Average (all days)	**85.3**	**94.8**	**94.6**	**95.1**

Maximum Aircraft Sound Levels

Figure 4.7 shows the overall distribution of aircraft induced Lmax sound levels (based on data collected over days 3 - 8). Maximum levels recorded over all sites ranged from 54 to 98dBA. Appendix 6.1 - 6.4 are the equivalent histograms for each site. All sites experienced similar overall ranges of Lmax, the most commonly recorded maximum sound levels at all sites were in the range of 60 – 64 dBA.

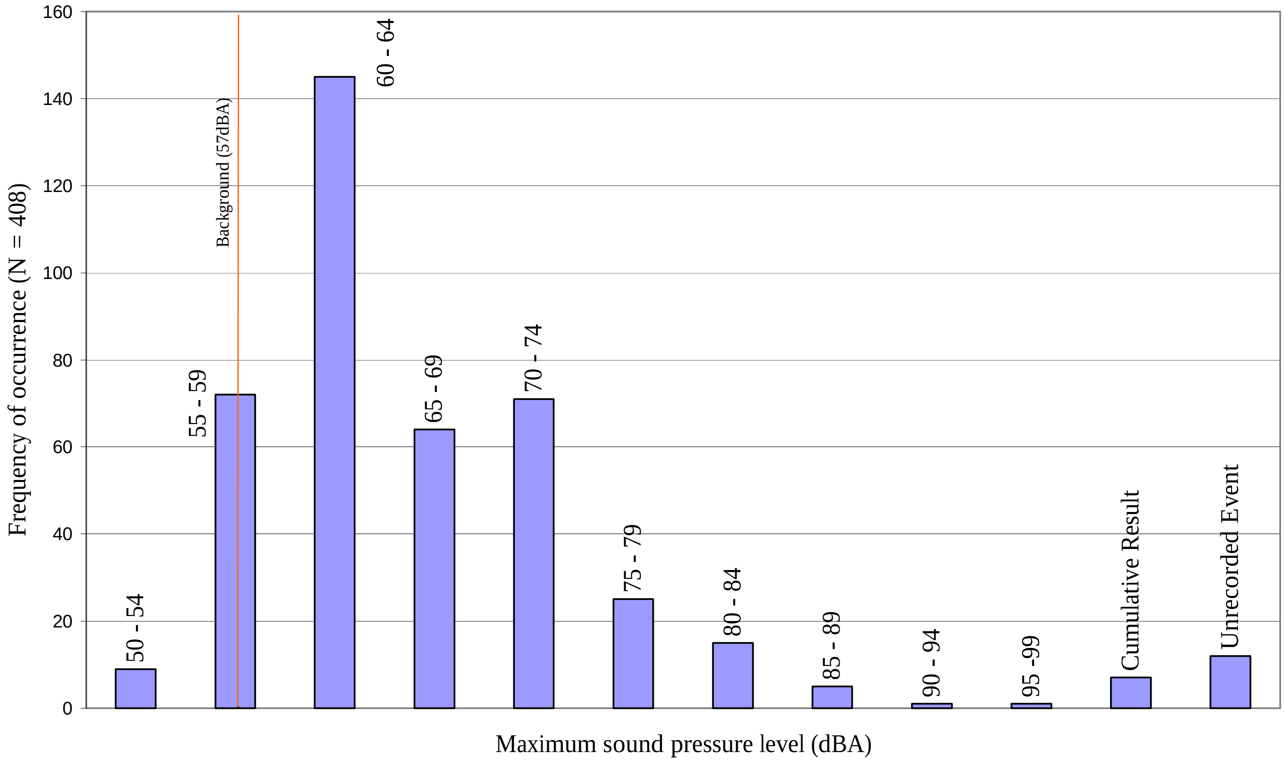

Figure 4.7. Distribution of maximum sound pressure levels over all sites.

Table 4.4 compares overall mean Lmax sound levels between sites and Figure 4.8 depicts mean Lmax sound levels at each site on each trip. Overall and on each trip site 4 recorded the loudest average sound levels followed by site 3, 2 and 5. The main difference between trips occurred at sites 2 and 5.

Table 4.4. Descriptive statistics of maximum sound levels at each site. Calculated from daily averages (days 3 - 8) at each site.

Site	Mean Lmax	N	Std. Deviation
2	63.82	93	7.06
3	66.77	111	7.21
4	67.85	110	7.95
5	63.30	94	6.80
Total	65.59	408	7.51

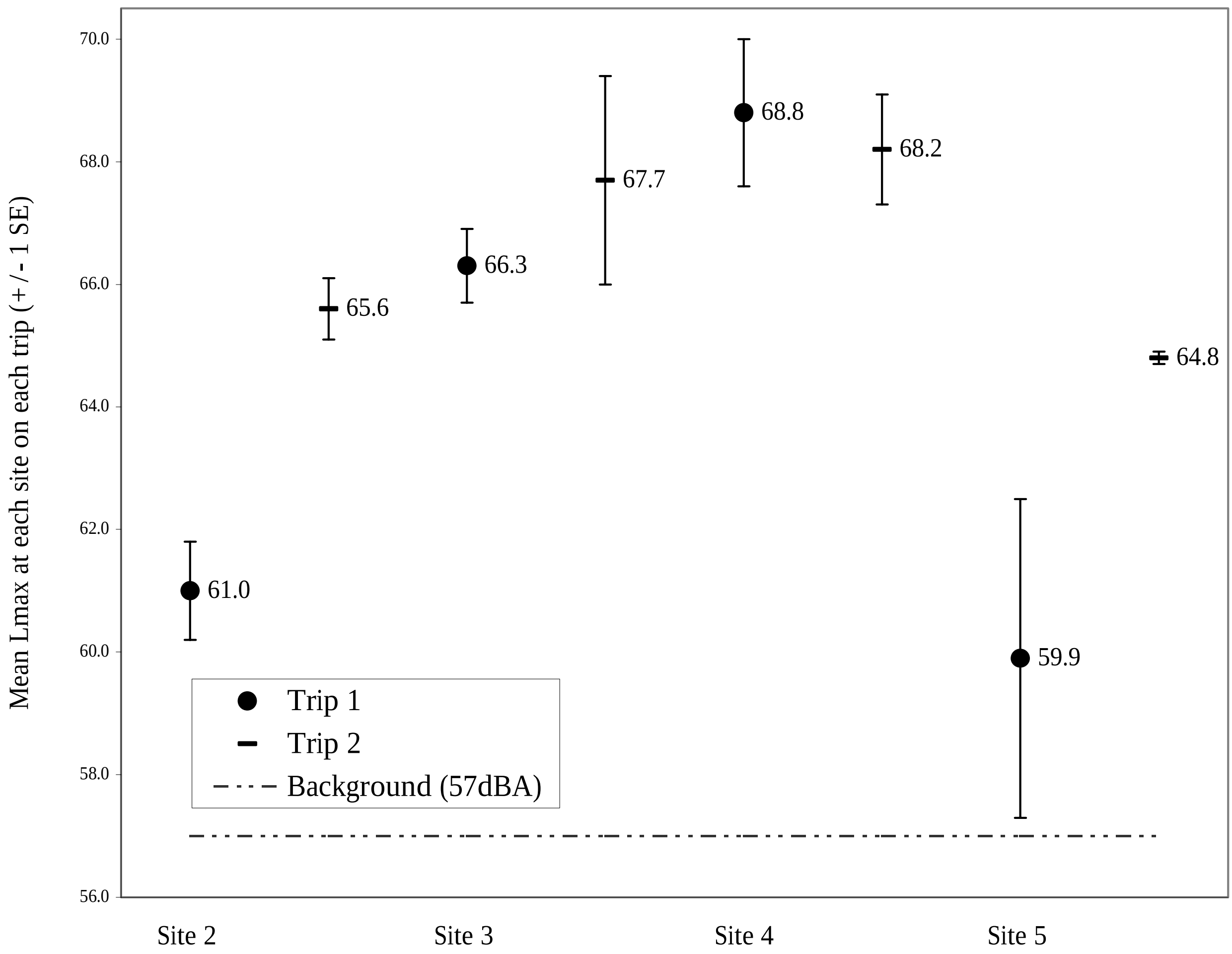

Figure 4.8. Mean aircraft Lmax recorded at each site on each trip (Error bars = +/- 1 SE). Results for trip 1 are calculated from daily averages on days 3 & 4 (due to wind induced noise on days 1 & 2). Results for trip 2 are calculated from daily averages on days 5 - 8.

The variation of aircraft induced sound levels relative to time of day is illustrated in appendix 6.5. Sites 2 and 4 experienced the highest average Lmax between 12:30 and 13:30, site 3 between 14:00 and 15:00, and site 5 between 16:00 and 17:00.

Figure 4.9 is based on data collected on days 9 and 10 (trip 3) and shows that seaplane takeoffs register the highest average maximum sound levels followed by helicopter flyovers associated with a landing or takeoff. Notably, far fewer helicopter events occurred than seaplane events and so the results regarding seaplane sound levels are based on a more comprehensive data base than those regarding helicopter sound levels. Distance between the sound source and the recorder was not standardised for these calculations although all seaplane takeoffs, landings and taxis occurred within 30 - 500m of observers. All helicopter events occurred within 50 - 200m of the observers. Seaplane flyovers occurred over an estimated range of several kilometres however the highest proportion were overhead or almost overhead.

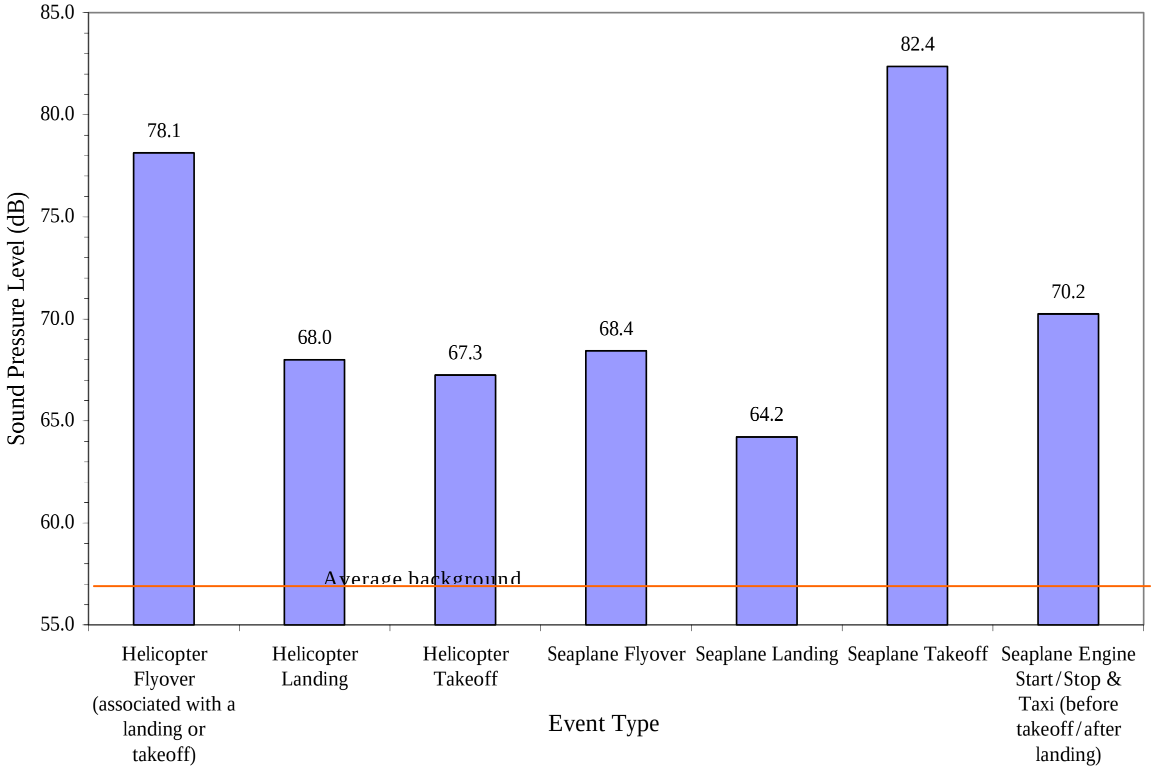

Figure 4.9. Average maximum sound pressure levels relative to event type. Results are compared with the average background sound level (57dBA) established on trips 1 and 2.

Data collected at all sites on days 3 - 8 shows seaplane 'takeoff flyovers' and helicopter 'takeoff flyovers' and 'flyover landings' to cause the highest sound readings (refer to appendix 6.7).

As depicted in figure 4.10 (based on data collected on days 9 and 10), increasing distance and increasing sound pressure levels are negatively correlated during seaplane takeoffs ($r = -0.635$ with 20df, therefore significant at $\alpha = 0.01$) (Assuming a normal (or approximating normal) distribution of x and y). As distance increases, decibel levels decrease. However, this is not a simple relationship, factors such as the type of aircraft and wind direction also influence sound levels. A stronger correlation would be expected for one type of aircraft under stabilised environmental conditions. Figure 4.10 shows that most sound levels above 84dBA occurred when the takeoff was within 300 meters of the observers.

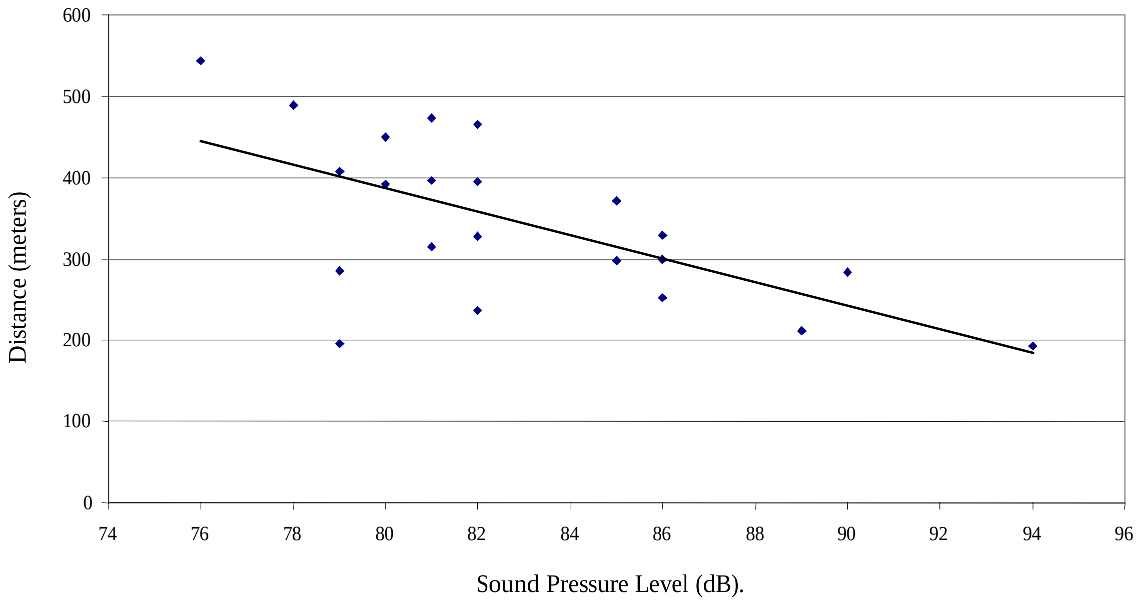

Figure 4.10. Relationship between distance and Lmax levels during seaplane takeoffs.

Duration of Aircraft Sound

Table 4.5 and figure 4.12 are based on data collected over days 3 - 8. Table 4.5 shows sites 3 and 4 to experience the greatest duration of aircraft noise followed by site 5 and site 2. Figure 4.11 shows that of the aircraft events which definitely started from and returned to background sound levels (only 19% of the events recorded), durations above average background sound levels ranged from 5 to 420 seconds with an average duration of 57 seconds. Appendix 6.6 shows the longest durations of aircraft noise above background sound levels to have occurred between 10:30 and 13:30.

Table 4.5. Durations of aircraft sound levels above background sound levels.

Site	Total Duration (min:sec)	Average Hourly Duration (min:sec)
2	88:42	2:52
3	189:00	6:06
4	206:58	6:41
5	95:25	3:05

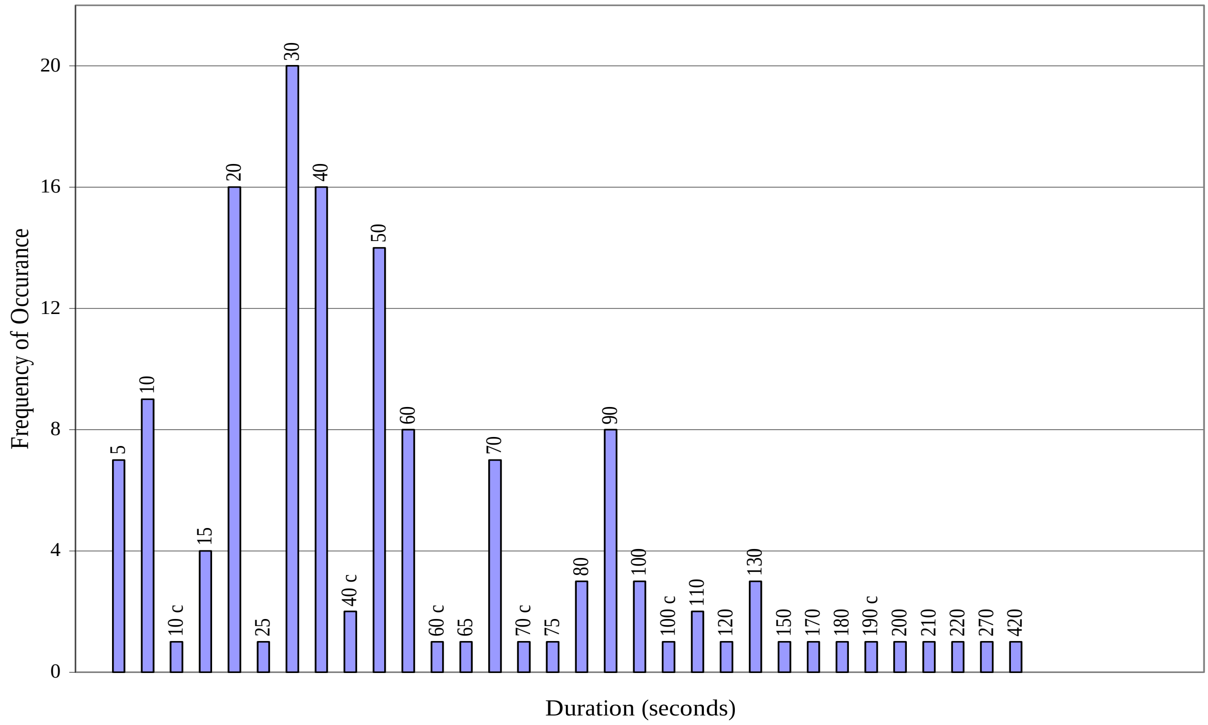

Figure 4.11. Durations of aircraft events in seconds. (Figures followed by a 'c' indicate that the result was cumulative, in other words, based on several aircraft events occurring simultaneously).

Other Anthropogenic Influences

In this section, data describing people and watercraft relative to the settings is presented. The purpose of these results is to allow aircraft activity and sound levels to be placed within the context of other anthropogenic influences at Whitehaven Beach.

Figure 4.12 shows that most of the people on the beach at 10:30 and 14:00 were in setting 2. Very few people were present in any of the settings at 17:00.

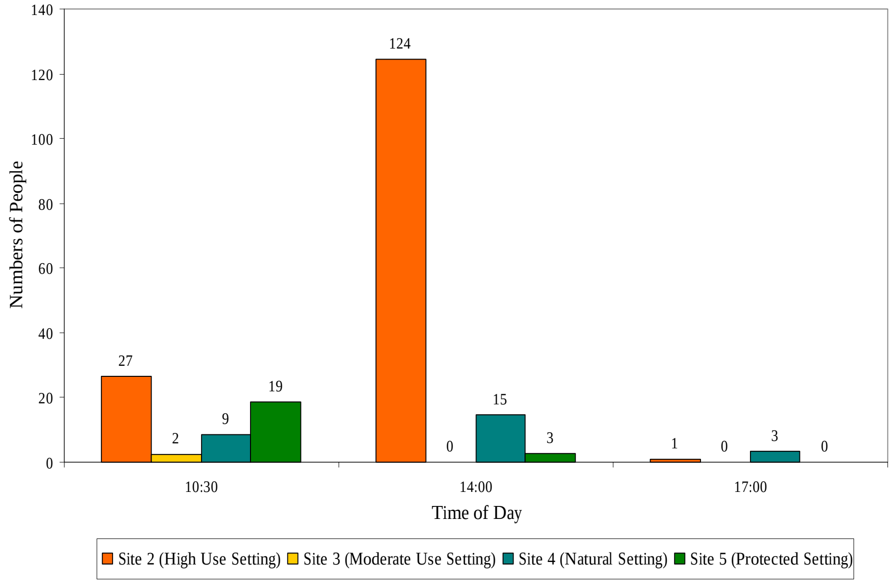

Figure 4.12. Average number of people within each setting at three set times of day. Based on data collected over days 5, 6 and 7.

Figure 4.13 shows that a similar average number of watercraft were noted to pass through each setting on each day, however the number of events considered significant enough to be recorded was much higher at site 2. This is not surprising as many more watercraft were observed to moor within setting 2 than at any other setting, while a high proportion of watercraft counted as visiting settings 3, 4 and 5 were yachts passing across the bay and having no sound impact at all. The greatest sound level recorded for watercraft was 79dBA while the longest duration recorded for a single watercraft event was 820 seconds (both were recorded at site 2). All types of watercraft events occurred in all settings and included yachts, large hydrofoils, speedboats and jet skis.

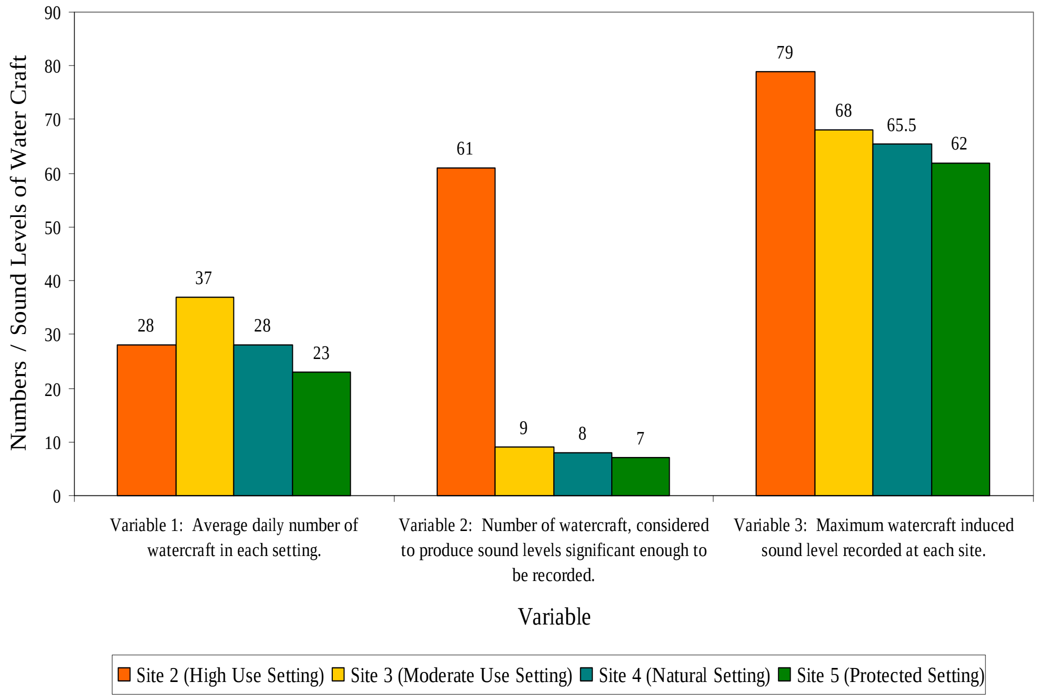

Figure 4.13. Variables indicating the activity and sound levels of watercraft at each site Variable 1 is based on 6 full days of data collection (days 1 -3, 5 -7). Variables 2 & 3 are based on data collected on days 3-8.

Summary of Results

Aircraft Activity

Overall site 2 experienced the fewest aircraft events followed by sites 5, 4 and 3. This trend was consistent between trips. To test this trend, a factorial analysis of variance was carried out on the factors 'site' and 'trip' with the variable 'hourly rate of visits'. Results for each day were treated as replicates within each site on each trip. Means and standard deviations at each site indicated a normal distribution. At a 95% confidence level no significant difference in hourly rates of visitation was found between sites or trips. Nor was there a significant interaction between sites and trips. However, sites were a greater source of variation than either trips or interaction (refer to table 4.6).

Table 4.6. Summary ANOVA table for the variable 'hourly visitation rates'. Data analysis was undertaken manually and in Excel. Data from days 4 and 8 was excluded from the analysis to reduce bias as sampling was undertaken only during the busiest time of day on these days.

Source of Variation	***SS***	***Df***	***MS***	***F***	***P-value***
Trips	0.926	1	0.926	1.523	0.235
Sites	4.492	3	1.497	2.463	0.100
Interaction	1.302	3	0.434	0.714	0.558
Residual	9.728	16	0.608		
Total	16.448	23			

The most common aircraft at all sites were seaplanes followed by helicopters. Site 2 received the greatest within site proportion of seaplane events and site 5 the greatest within site proportion of helicopter events. The morning was the busiest time of day peaking between 11:30 and 12:30 with an average of 4.7 - 6.2 flights per hour over all sites. Aircraft were observed between 07:00 and 17:00. Seaplane events were most common in the morning. Other event types did not show a trend of activity relative to time of day. 71% of all aircraft events at Whitehaven Bay affected 3 or 4 of the sites.

Aircraft Sound

Natural Sound Levels

Natural sound levels were lower at site 5 than at the other three sites. Reasons for this may be related to topography and subsequent wind exposure, proximity to the high tide mark, and the presence/absence of wildlife. The overall average natural day-time sound level on the land ward side of Whitehaven Beach is calculated to be 57dBA. However, the actual average is thought to be in the range of 50 - 55dBA (based on comparative measurements made with a more sensitive sound meter). These results are consistent with recordings made in the USA and predictions for sites situated close to surf and exposed to wind (Fidell et al. 1990; Bowlby et al. 1990; US Forest Service 1992).

To statistically test differences between sites, a factorial analysis of variance was carried out. Means and standard deviations at each site indicated a normal distribution of the data. Assuming a decibel range of 0 - 110dB.

The analysis of variance supported the observation of a significant difference between sites but not between trips. Nor was there a significant interaction between sites and trips ($\alpha = 0.05$) (refer to table 4.7).

Table 4.7. Summary ANOVA table for natural sound levels between sites. Based on two days of data from trip 1 and four days of data from trip 2 (averaged over two days to give equal sample sizes for each trip). Analysed manually and in the spreadsheet program Excel.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Trips	2.480625	1	2.480625	1.343829	0.279788
Sites	29.87563	3	9.958542	5.394842	0.025251
Interaction	7.280625	3	2.426875	1.314711	0.335264
Residual	14.7675	8	1.845937		
Total	54.40437	15			

Aircraft Sound Levels

At sites 3, 4 and 5, 95% of aircraft events registered above background sound levels and at site 2, 85% did so. Maximum decibel levels recorded for aircraft events ranged from 54dBA - 98dBA over all sites. This result is consistent with recordings made in US National Parks (47dBA - 107dBA), which was previously discussed in the review of related studies. The most commonly recorded maximums at all sites were within the range of 60-64dBA. Site 4 recorded the highest average Lmax (68.8dBA) followed by sites 3, 2 and 5 (59.9dBA). This trend was consistent between trips. Overall average peak decibel levels were higher than those recorded by Tabachnick et al. (1994) who calculated average peak levels in parks in the US to be from 53 - 64 dBA. Results of this study compared to those of studies undertaken in the US are not surprising. US studies recorded higher maximum peaks presumably because they experienced military jet overflights and lower minimum peaks presumably because they used more sensitive sound meters. This study recorded higher overall average peak sound levels possibly because aircraft take-offs were included in this study but not in that undertaken by Tabachnick et al. (1994). A factorial analysis of variance showed a significant difference between both trips and sites but not a significant interaction of sites and trips ($\alpha = 0.05$). Most of the difference between measurements was due to between site variation (refer to table 4.8). A Q-Q plot of standardised residuals confirmed that the data approaches a normal distribution (refer to figure 4.14).

Table 4.8. Summary ANOVA table for Lmax between sites and trip. Based on two days of data from trip 1 and four days of data from trip 2, analysed using SPSS.

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*
Trips	34.994	1	34.994	8.374	.011
Sites	136.993	3	45.664	10.928	.000
Interaction	28.342	3	9.447	2.261	.121
Residual	66.859	16	4.179		
Total	241.599	23			

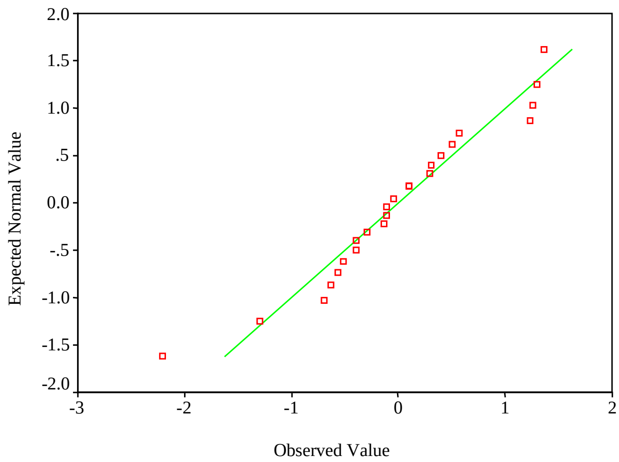

Figure 4.14. Normal Q-Q plot of standardised residual for Lmax.

The noisiest times of day varied between sites. Seaplane takeoffs were the loudest recorded event type followed by helicopter flyovers associated with a landing or takeoff (low flying helicopters). These results are consistent with the work of Fidell et al. (1992) who found helicopter and military jet flyovers to cause the highest sound readings. Aircraft takeoffs were not included in their study. A strong correlation was found between distance from the sound source and sound levels experienced during seaplane takeoffs.

Sites 3 and 4 recorded the longest duration of aircraft sound above average background sound levels and sites 2 and 5 recorded the shortest duration. The average duration of aircraft sound levels above background sound levels is calculated to be 57 seconds. This result is consistent with the work of Fidell et al. (1992) who described propeller planes as typically having a duration of 60 seconds above background sound levels. The longest recorded duration was 420 seconds.

Other Anthropogenic Influences

The majority of the people on the beach at 10:30 and 14:00 were in setting 2. Few people were recorded in any setting at 17:00. Chi squared analysis comparing settings 2 and 3 against settings 4 and 5 at 10:30 and 14:00 gave a significant result ($\alpha = 0.05$). Settings were grouped in order to meet the constraints of the analysis (refer to table 4.9 for a summary of the analysis). This analysis assumes independence between samples taken at 10:30 and 14:00. Based on observations (people generally spent less than 3 hours on the beach), this is considered to be a reasonable assumption.

Table 4.9. Summary table of χ^2 analysis, number of people between sites and times.

Sites	10:30		14:00		Totals
	Observed	Expected	Observed	Expected	153
2 & 3	29	44	124	109	46
4 & 5	28	13	18	33	199
Totals	57		142		

Using Yates' correction for d.f. = 1, $\chi^2 = 30.84$ ($p > 0.001$).

A similar number of watercraft were recorded passing through each setting. However, the number of watercraft events considered loud enough to warrant recording was much higher at site 2 than at all other sites. The highest watercraft sound level was 79dBA and the longest duration above average background was 820 seconds. All types of watercraft occurred in all settings and included jet-skis, speed boats and large hydrofoils.

For both the anthropogenic influences of people and watercraft, the main difference between sites / settings occurred between site / setting 2 and all other sites / settings.

DISCUSSION

Trends in Aircraft Use

Results of the analysis of aircraft sound and activity at Whitehaven Beach are of the most value to management when placed within the context of other sound sources and activities as well as the relative use level at the time of the field survey. Figure 5.1 depicts trends in aircraft use of Whitehaven Beach from July 1997 until June 1998. Assuming that the same relative levels of use occurred at the time of the field survey for this study, the results of this study (data collected in October and December 1998) represent lower levels of aircraft noise and activity experienced at Whitehaven Beach over a year. This conclusion is supported by local knowledge (McLeod, *pers. comm.*, 1998).

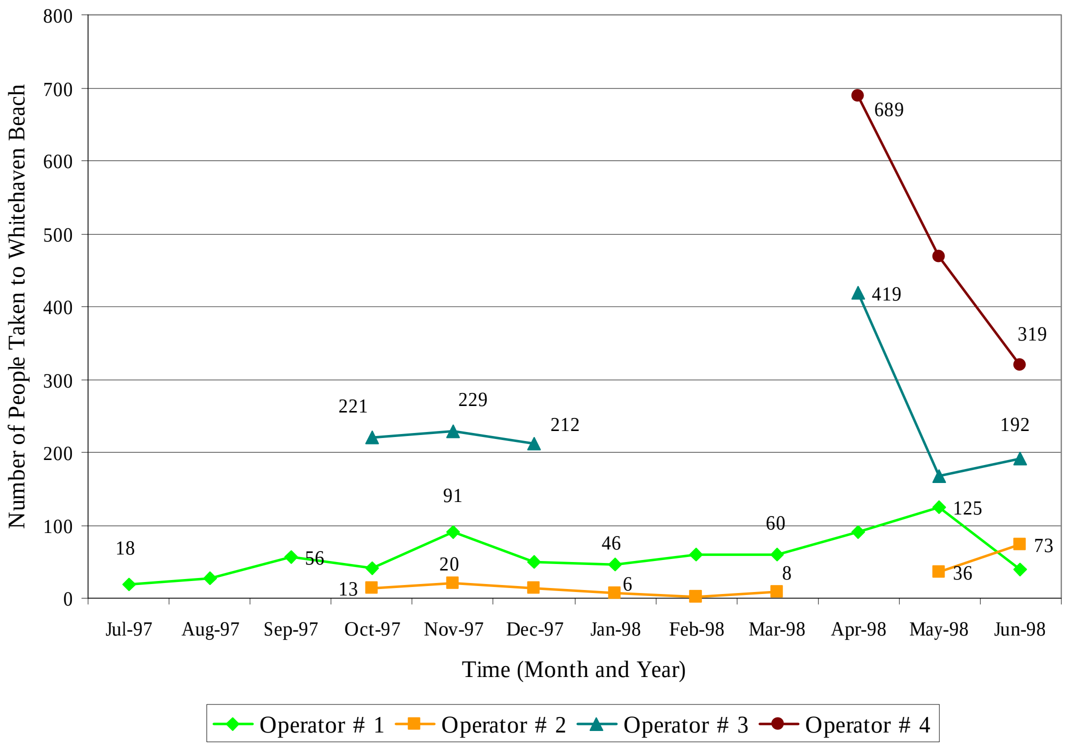

Figure 5.1. Trends in use of Whitehaven beach by several air tour operators *(Source: GBRMPA Environmental Management Charge Data)*

Discussion of Results

Noise and the ROS Spectrum.

Recreation opportunity spectrum settings are designed to provide a range of user experiences aimed at satisfying a variety of user expectations. In order to do so, all variables influencing the setting type need to meet the expectations laid down by the setting definition. Thus in the case of Whitehaven Beach one would expect the high use setting to receive the highest levels of use by all user types followed by the moderate use setting, the natural setting and the protected setting which would receive the lowest levels of use. Indeed, as detailed in the description of the study sites, the Whitsunday's Plan of Management (GBRMPA 1998) defines the ROS settings in these terms.

The results of this study show that in the case of aircraft at Whitehaven Beach, site 2 (representing the high use setting) experienced both the lowest levels of visitation, duration of aircraft sound levels above background sound levels and proportion of aircraft visits registering above background sound levels. Average Lmax sound levels at site 2 were slightly higher than those recorded at site 5 (protected setting). Sites 3 (moderate use setting) and 4 (natural setting) experienced the highest numbers of visits, highest average Lmax sound levels and longest durations with equivalent proportions of aircraft visits registering above background sound levels as at site 5. Subsequently, in terms of aircraft activity and noise levels along Whitehaven Beach, a trend inconsistent with that predicted by the definitions of the settings within which the sites are situated is apparent.

As the aircraft landing zones along Whitehaven Beach occur in the moderate and natural settings (although aircraft were observed to land and takeoff in all settings), it is not surprising that these settings receive the highest levels of aircraft use and noise exposure. This issue is related to planning, as landing zones have been established in settings designated to experience very few aircraft visitations. The presence of a landing zone on the northern side of Hill Inlet within setting 5 further contradicts the description of Hill Inlet as being protected from access by aircraft (GBRMPA 1998). Furthermore, the small size of the ROS settings along Whitehaven Beach is expected to reduce their ability to maintain distinct characteristics in line with their definitions. The fact that motorised water sports and aircraft landings / takeoffs were observed to occur beyond their designated areas of activity would also have influenced results and highlights a problem of regulation enforcement.

The main difference in human and watercraft use of the beach occurred between site 2 (high use setting) and all other sites, with site 2 experiencing much higher levels of use than all other sites. Thus for these variables the ROS spectrum appears to be functioning in line with expectations. However, a gradient in human and watercraft use in line with the definitions of the ROS settings was not apparent between sites 3, 4 and 5.

Noise and Time of Day

The recreation opportunity spectrum is primarily a method of spatial planning, however, temporal planning, using methods such as curfews and seasonal restrictions, is often incorporated into it. Thus, the same spatial area may undergo a range of use regimes relative to time. Seasonal restrictions and curfews are currently in use in the Whitsunday Islands (GBRMPA 1998) (McLeod *pers. comm.*, 1998) and the settings along Whitehaven beach experience temporal changes in levels of use due in part to regulations governing times of use.

The busiest time of day for aircraft at Whitehaven Beach was recorded as being in the morning peaking between 11:30 and 12:30. The longest durations of noise were also recorded within this time frame. However, the loudest average sound recordings made at each site did not show a unified trend relative to time of day. Rarely were aircraft observed before 07:00 or after 17:00.

Many more people were recorded as being on the beach at 14:00 than at 10:30 and observations showed that most of the people present in setting 2 at 14:00 arrived in the hydrofoil *'Fantasea'* at roughly 13:00 and left the beach at approximately 16:00. Few people or watercraft were present on the beach or in the bay before 09:00 or after 17:00.

Aircraft versus Watercraft.

As mentioned earlier, results of the analysis of aircraft sound and activity at Whitehaven Beach are of the most value to management when placed within the context of other sound sources and activities. In the case of anthropogenic noise at Whitehaven Beach the two sources assumed to be most obvious to recreationists are watercraft and aircraft. However, comparisons of the potential intrusiveness of these noise sources are not straight forward.

The absolute maximum watercraft induced decibel level recorded was 79dBA compared to 98dBA recorded for aircraft. This suggests that aircraft have a greater noise impact. However, maximum decibel levels and audible duration are potentially equivalent variables impacting recreationists at Whitehaven Beach. Although the duration of watercraft noise events was not rigorously measured (as the focus of the study was on aircraft), the longest duration recorded for a single watercraft noise event was almost twice that recorded for the longest single aircraft noise event. This suggests that although watercraft emit lower maximum sound levels than aircraft, their average duration may be longer. Subsequently, watercraft potentially have an equivalent or greater sound impact than aircraft.

Mitigation

Methods of noise mitigation was not a focus of this study although mitigation methods used in and recommended for National Parks in the USA were discussed in the review of related studies. One method of mitigating noise of both overflights and takeoffs is derived from the relationship between distance from the sound source and the sound level experienced by a listener. This relationship was investigated at Whitehaven Beach for seaplane takeoffs. Results showed that all maximum sound levels above 89dBA were recorded when the aircraft was within 300m of the recorders, and all maximum sound levels below 78dBA were recorded when the aircraft was 500+m from the recorders. Thus, as an increase in ten decibels is perceived as being twice as loud (Standards Australia 1988), this result suggests that a relatively short increase in the distance between a takeoff and an observer (e.g. from 300m to 500m) potentially reduces the noise impact by at least half. This also raises the issue of other mitigation measures including, quieter aircraft technology, noise budgets and the expansion of flight free areas.

Technology, Survey Design and Analysis

Ideal Technology

The Techcessories analogue sound meters upon which differences in sound levels between sites were based did not meet Australian Standards for either type 0, 1, 2 or 3 sound level meters. However, as stated in the Standards, they may be considered satisfactory for particular applications (Standards Australia 1988) which presumably includes indicative studies such as this one. The integrated type 2 meter used to give comparative and theoretically more accurate readings was itself past calibration date and when tested shown to be reading 1.8 dB lower than it should have been. Thus, it too did not meet Australian Standards. Subsequently, results from this study are only indicative of sound levels experienced at Whitehaven Beach and can legally only be used to help decide the need for more comprehensive research.

Preferably the sound meters used would have at least met the Australian Standards for type 0 or 1 meters including specifications for use in the field. Sound meters specifically designed to accurately measure sound levels below 20 - 25dB (and therefore capable of establishing the level of extreme quiet) would have been even more ideal.

Survey Design

Strategy

This study was constrained due to the small size of the study area. The proximity of measurements to one another meant that they were not truly independent of each other, thus limiting the use of quantitative analysis. Used on a larger spatial scale such as the whole of the Whitsunday Islands, the survey methodology would be expected to be more meaningful. However, as the main objective was to determine differences between settings along Whitehaven Beach, it was unavoidable that data collection sites would be in close proximity to one another as the adjoining settings themselves are only between 1 - 2 kilometres wide. This highlights the point that ROS was originally intended for use on a regional scale (Manning 1986). Use on a larger scale can be assumed to result in less edge effect within setting areas and a better means of satisfying diverse users.

Data collection sites were not replicated within each setting. Thus results only represent conditions at the site within the setting at which measurements were made. Although these conditions can be hypothesised to represent the setting overall (or at least the core of the setting), this study provides no substantiated evidence of this.

Logistics of Data Collection

Sound Recordings

As sites were not necessarily equidistant from the high tide mark this may have affected background readings and the level to which aircraft sound was masked. The inability to always eliminate wind noise readings from the calculation would also have influenced sound level recordings. Sound made by the data recorders while making analogue recordings may have influenced integrated type 2 sound meter recordings.

Sound meter calibration errors may also have affected results. All sound meters were calibrated prior to and after each field trip. After the second trip the sound meter for site 4 was reading 0.5 dB lower than the others. Results were not adjusted accordingly due to the inability to determine when this difference in reading occurred while for the purposes of this study a difference in 0.5dB is not considered crucial to the main results.

A-weighted networks and fast response settings were used for all sound recordings. Fast response settings were certainly necessary when recording aircraft and watercraft sound levels as one of the aims was to determine peak levels. Slow response settings may have been a better means of establishing background sound levels. Using a slow response would have eliminated much of the affect of outlying readings and given a truer average.

Significant Watercraft Events

Sites may not have been equally likely to record 'significant' watercraft events while the definition of a significant watercraft event was subjectively determined by data recorders. Sites experiencing higher numbers of aircraft events presumably had less time to record watercraft events, subsequently biasing the results. Notably site two experienced the lowest number of aircraft events while recording many more watercraft events than any other site. Nevertheless, the result for site 2 has a great deal of room for error while continuing to remain substantially different from the other sites. Also, results are consistent with the personal observations of the researcher plus those of Ormsby and Shafer (1999), who found setting 2 to be the most frequently visited setting by both people and watercraft.

Individual Variability

Individual variability in methods of data collection probably influenced results. Variability due to differences in eye sight and hearing of the observers may have resulted in differences in the methods of recording the number of aircraft events. This is probably especially true for sites 3 and 4 which, due to their location in the middle of the beach, were inclined to be border line for experiencing one versus two events. For example, an aircraft flies over a site and later returns to land but is recorded as one event because it remained within audible/visual range despite having two distinct peak sound levels. Also, when taking sound level readings, observers may have had a tendency to read even rather than odd numbers as even numbers were more clearly defined on the analogue sound meters.

Estimations of duration are considered to be the variable most influenced by variations in data recorder technique. Some individuals were observed to be more conscientious about recording the full length of an aircraft event than others. Furthermore aircraft could not be recorded from before they came into hearing range or even from when they first came into hearing range. The amount of time lost being partially dependent on the response rates of the observers. At least 10 seconds is estimated to have been lost for most events.

When establishing the relationship between aircraft takeoffs and distance from the beach during the third data collection trip, error may have occurred due to discrepancies between the timing of sound and distance readings. Although these were intended to be taken concurrently, variations in the order of a few seconds very likely occurred.

Analysis

Descriptive

Sound

Results of aircraft sound variables are compared with the overall mean background sound level of 57dBA. If this level is lowered to 52dBA (the mean suggested by measurements made with the integrated sound meter), values of the variables: durations of aircraft sound; overall proportion of aircraft visits registering above background sound; and the difference between natural and aircraft sound levels, increase at all sites.

Limitations of the A-weighted network as discussed in appendix 7.2 may have resulted in an underestimation of the loudness perceived by observers. However as the A-weighted network has been used in all related studies so far, results are comparable to these studies. As discussed in appendix 7.5 in reference to Anderson and Horonjeff (1992), the use of the acoustical descriptors Lmax and Leq versus audibility metrics, potentially result in a conclusion of less value in increasing altitude for mitigation purposes. However, in light of the high ambient background sound levels experienced at Whitehaven Beach as a result of surf and wind, increases in altitude can be expected to result in a significant reduction in sound impact, when impact is measured using audibility metrics (e.g. percent of time audible).

As only 19% of aircraft events definitely started from and returned to background sound levels this implies that 'duration above background' was a relatively inaccurate variable to measure. Possibly either because events had durations greater than those recorded or because higher than average background sound levels interfered with the calculation. The method of multiplying the number of readings registering above average background sound level by a factor of 10 in order to estimate duration, also has room for error as sound levels did not necessarily steadily increase and then decrease during an event, some fluctuated substantially.

Duration of aircraft induced sound levels above background sound levels is also considered to be unreliable as a means of indicating potential levels of noise impact on recreationists at Whitehaven Beach. This is primarily because aircraft were observed to be audible for much longer than they are recorded as being above background sound levels. This observation is consistent with the results of studies done in the US (US Forest Service 1992; US National Parks Service 1994).

Environmental Conditions

Site four, the site at which wind data was collected was assumed to be representative of wind regimes over the entire beach. However, given the non-uniform topography of the beach, this assumption may not be valid.

Trends in Activity

Trends of aircraft activity are extrapolated from trends in the numbers of people taken to Whitehaven beach by aircraft. Although there is undoubtedly a positive correlation between these two factors, there is also room for error.

Statistical

Conclusions drawn by this study are primarily based on descriptive results. Where statistical tests have been undertaken, their validity is dependent on the accuracy of assumptions about the data as referred to in the summary of results section. The use of analysis of variance is based on an assumption of normal or approximating normal distribution which was tested whenever analysis of variance was used.

The use of non-parametric statistical tests to compare results of sound levels and numbers of events between sites, was primarily inhibited by the inability to assume independence of the samples due to the proximity of the sites to one another.

Measuring Impacts (Sound or Noise)

In order to measure impacts of aircraft noise on recreationists rather than just the environmental phenomenon sound or its related variables, it is necessary to directly correlate sound levels or related variables with human response. Thus, concurrent studies such as those by Fidell et al. (1992), Anderson et al. (1993) and Tabachnick et al. (1994) and discussed in the review of related studies, need to be undertaken. In these studies sound metrics such as 'percent of time audible' and 'Leq' were measured concurrent with onsite interviews taking place. Thus, allowing dose-response relationships to be established.

If a dose-response relationship was established for Whitehaven Beach, it would then be possible to predict impact in similar areas by measuring sound / noise variables. As studies done in the USA have shown that the sound metric 'percent of time audible' most accurately indicates level of response, it may not be necessary to use sound meters at all to develop a dose-response curve for aircraft noise at Whitehaven Beach.

Ormsby and Shafer (1999) concluded that only approximately 10% of people were adversely affected by aircraft, watercraft or crowding on Whitehaven Beach and that the natural and scenic qualities of Whitehaven Beach were attributes that visitors received the most enjoyment from. Unfortunately this study and that of Ormsby and Shafer (1999) were not undertaken at the same time and so the results cannot be directly correlated. Aircraft activity was lower during Ormsby and Shafer's data collection period and weather conditions were poorer. Dose response studies undertaken in the USA did show that an increase in dose resulted in an increase in response (US National Parks Service 1994) and Brown's (1986) work at Green Island supports this. Thus it is fair to assume that a similar scenario is likely to occur at Whitehaven Beach.

Recommendations for Future Studies

Recommendations for future studies in the Whitsunday Islands and Australia generally are based on four factors: sound meters; sound metrics; survey periods; and the positioning of sites.

As discussed in appendix 7.1 sound meters should at least meet Australian Standards for integrated types 0 or 1 including specifications for use in the field. Results obtained would then meet legal requirements for decision making in Australia. However it would be preferable to use sound meters capable of measuring sound levels below 20 - 25dB (the usual limit for sound levels used in community sound studies) (Horonjeff et al. 1993; US National Park Service 1994). If analogue Techcessories sound meters (or an equivalent sound meter type) are used again for indicative studies, the use of a slow response setting to measure background sound level averages is recommended as well as the use of windshields at all times.

Sound metrics used (refer to appendix 7.3) depend somewhat on the type of sound meter. Integrated sound meters would allow the measurement of Leq and the subsequent calculation of Ldn. Comparisons between 'total' (all sources) Ldn and either 'aircraft only' or 'indigenous only' Ldn could then be made, as discussed in the methods used to monitor and assess overflights section, in reference to work reported by Bowlby et al. (1990) and the US Forest Service (1992). Sound meters could also be programmed to record once a trigger sound level was reached and subsequently the study would not heavily rely on volunteers to collect the data. The use of the sound metric 'percent of time audible' is highly recommended particularly in the absence of high quality sound level meters. Use of the metric 'percent of time audible' would; simplify data collection, reduce reliance on expensive technology, and provide a means to most accurately predict human response. However, data collection using the metric 'percent of time audible' would heavily rely on the availability of volunteers meeting set hearing requirements. The use of either the metric 'Leq' or 'percent of time audible' undertaken concurrently with social surveys would allow for the development of dose-response curves.

Periods of data collection complying with those recommended by DeVor et al. (1979), Schomer and DeVor (1981) and Schomer et al. (1983) and used by Bowlby et al. (1990) (discussed in appendix 7.4) are also recommended. Possibly four week long periods corresponding to distinct seasons of use.

Data collection sites should be replicated within settings and placed over a wider spatial scale to ensure independence between them. If reassessing sound levels along Whitehaven Beach, other sites within equivalent settings at other locations in the Whitsunday Islands should also be assessed. Replication within settings which are geographically independent would also allow an assessment to be made of the consistency in characteristics between settings of the same type.

CONCLUSION

It is concluded that, in terms of aircraft activity and noise levels along Whitehaven Beach, a trend inconsistent with that predicted by the definitions of the ROS settings is apparent. The high use zone receiving the lowest levels of use and noise exposure and the moderate and natural use zones receiving the highest levels of use and noise. This appears to be related to planning for the area as aircraft landing zones have been established in settings designated to receive minimal aircraft activity while the ROS settings themselves comprise small spatial areas. However, there also appears to be a problem of compliance with restrictions on access to settings. For example, aircraft takeoffs occurred beyond designated zones as did motorised water sports. For the anthropogenic influences of watercraft and people, the high use setting received the most use, consistent with expectations. However, a gradient in human and watercraft use in line with the definitions of the ROS settings was not apparent between the other settings. Aircraft were found to register the highest decibel levels of any sound source on the beach with peaks ranging from 0 - 40dBA above average natural sound levels. Yet, due to their greater durations of noise, watercraft potentially cause an equivalent or even greater noise impact on recreationists at Whitehaven Beach than aircraft.

It needs to be stressed that the levels of use recorded by this study were based on data collected during a low season of air tours to Whitehaven Beach while one of the loudest aircraft noise sources (low flying military jets) reported to over fly Whitehaven Beach, were not observed during the course of this study.

As growth in the tourism industry continues in Australia, natural quiet is in danger of becoming an increasingly rare resource in protected areas valued by visitors for their natural and scenic qualities. Motorised sources of sound such as air and water craft are responsible for much of the loss in natural quiet in protected areas. Although aircraft activity and sound levels at Whitehaven Beach do not appear to emulate levels experienced in some other protected areas, notably the Grand Canyon, it would be wise to remember that prevention is always better than cure.

RECOMMENDATIONS

It is recommended that GBRMPA continue working toward comprehensive aircraft management policy development for the Great Barrier Reef Marine Park and this study be used as partial justification for a more comprehensive baseline and monitoring study of aircraft and watercraft at Whitehaven Bay and in the Whitsunday Islands generally. Any future research should meet Australian Standards for sound measurement, thus, allowing results to be used for decision making with legal implications.

Prior to undertaking further research, it is advised that GBRMPA consider:

- Its expectations for the ROS settings throughout the Marine Park in terms of aircraft / watercraft activity and noise.
- Appropriate current and future levels of use at Whitehaven Beach particularly in light of the beach's designation as a sensitive site.
- The possibility of developing dose response curves.
- The need for ROS planning on a larger geographic scale than that at Whitehaven Bay.

As part of future research, it is advised that GBRMPA further investigate:

- Flight paths and takeoff positions which would result in the most acceptable impact within the ROS settings along Whitehaven Beach and in the Whitsunday Islands generally.
- Potential noise mitigation measures including distance (height) of the sound source from the listener, phasing in the use of quieter aircraft technology and the potential for developing fly neighbourly policies with local operators.

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APPENDICES

APPENDIX 1.0. Symbols Used to Describe Aircraft and Watercraft Events.

*	Late reading.
^	Helicopter (by itself it means that a helicopter has come into view, otherwise it is used in combination with other symbols).
#	Seaplane (by itself it means that a seaplane has come into view, otherwise it is used in combination with other symbols).
$	Unspecified light aircraft (by itself it means that an unspecified light aircraft has come into view, otherwise it is used in combination with other symbols).
+	Watercraft (by itself it means that a watercraft has come into view, otherwise it is used in combination with other symbols).
~	Directly in front (therefore out to sea).
~~	Directly behind.
@	Directly overhead.
!	Almost overhead.
{	Entered setting.
}	Exited setting.
>	Disappeared from view.
%	Seaplane taxing.
/	Landing.
"	Take-off.
=	Wind gust.
;	People sounds.
( )	Occurred between the ten second readings.

APPENDIX 2.0. Survey Proforma

Background Sound Levels

Date: Site (2,3,4 or 5): Data collectors names: Weather:

Time	Decibel level (A-weighted / fast)	Notable Source *	Time	Decibel level (A-weighted / fast)	Notable Source
8.00			12.45		
8.15			1.00		
8.30			1.15		
8.45			1.30		
9.00			1.45	BREAK	
9.15			2.00		
9.30			2.15		
9.45			2.30		
10.00			2.45		
10.15	BREAK		3.00		
10.30			3.15		
10.45			3.30		
11.00			3.45		
11.15			4.00		
11.30			4.15		
11.45			4.30		
12.00			4.45		
12.15			5.00		
12.30			* E.g. notable source = Power boat ~ 100m off shore, bird, wind, human …		

Aircraft events.

Date: Site (2,3,4 or 5): Data collectors names: Weather Conditions:

#	Start Time (hr:min:sec)	Decibel (A-weighed / Fast) recordings every 10 seconds plus maximum.	Finish Time (hr:min:sec)	Event occurred within own zone (yes/no)	# of landing zones away from monitoring point aircraft landed (to L or R) (e.g. 2 L)	Notes: • Type of aircraft (helicopter, seaplane…); • Flyover (F), flyover and landing (FL)...

Significant Watercraft Events.

Date: Site (2,3,4 or 5): Data collectors names: Weather Conditions:

#	Start Time (hr:min:sec)	Decibel (A-weighted / fast) recordings every 10 seconds plus maximum	Finish Time (hr:min:sec)	Event occurred within own zone (yes / no)	Notes: Notable Source (e.g. Power boat ~ 100m off shore)

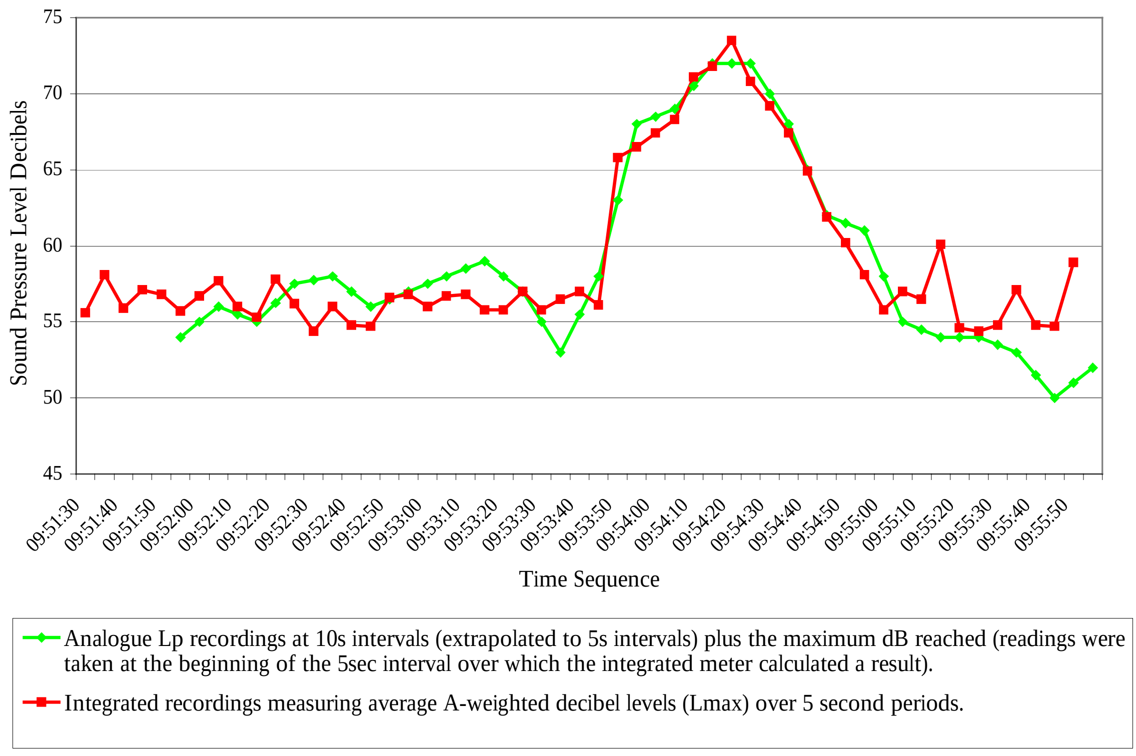
Temperature, Humidity, Wind Speed and Direction.

Date: Site: Data Recorder(s):

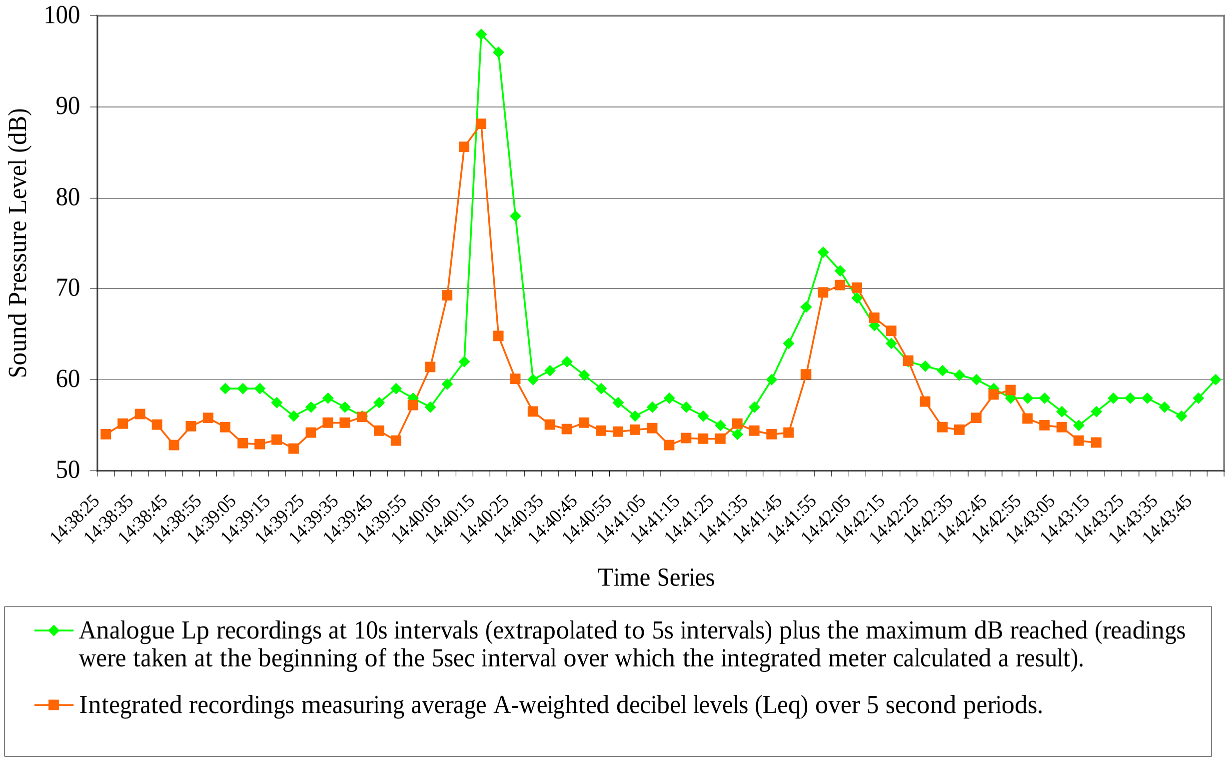
	WIND DATA			TEMP DATA	HUMIDITY DATA
START TIME	DURATION	FEET	DIRECTION	TEMP (^{o}C)	HUMIDITY (%)

APPENDIX 3.0. Instrumentation.

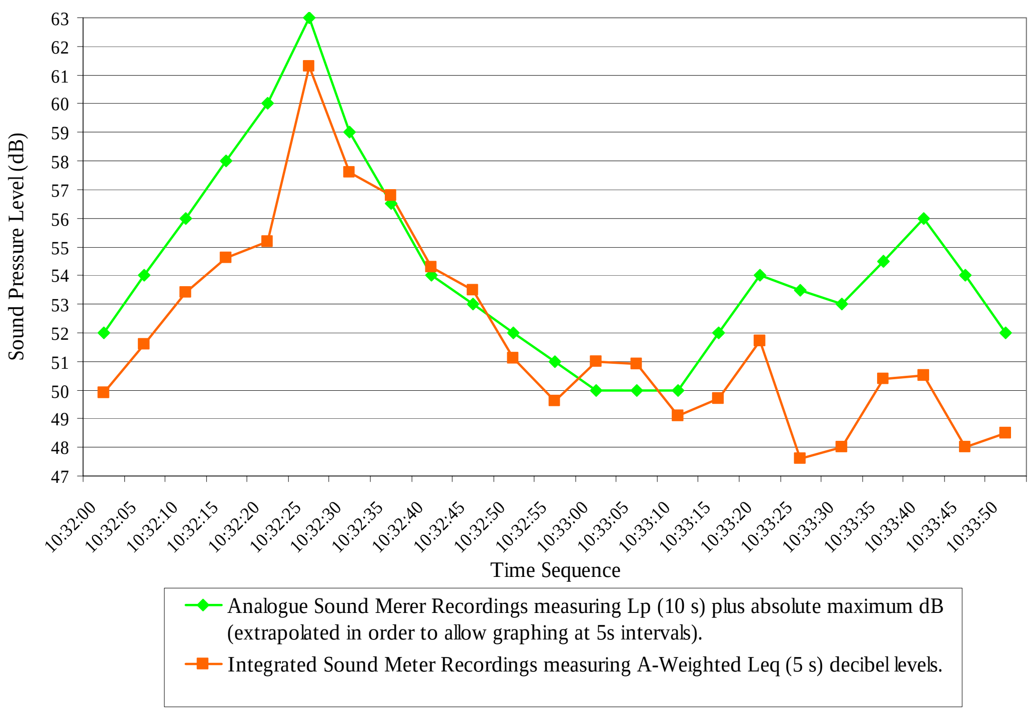
In this appendix a comparison is made between recordings made with an analogue sound meter and those made with the digital integrated type 2 sound meter for three aircraft events. The purpose being to help establish the accuracy of the analogue meters and the differences between the recording methods. The integrated meter recorded sound continuously and stored Lmax (calculated over 5 second periods) or Leq (calculated over 5 second periods) readings. Analogue meters measured Lp sound levels at ten second intervals. They also recorded the absolute maximum sound level reached during an aircraft event. Analogue recordings were extrapolated to allow plotting at 5 second intervals. Analogue meter Lp readings were taken at the beginning of every 2nd 5 second interval for which a recording was made with the integrated meter. Subsequently, the two types of recordings plotted together do not actually correlate in time precisely as is suggested by the graphs, and nor are they measuring exactly the same sound variable. Nevertheless, in all graphs, the variables plotted show similar trends.



Appendix 3.1. Comparison between analogue (measuring Lp) and integrated (measuring Lmax) sound meter recordings of aircraft event 146 at site 3.



Appendix 3.2. Comparison between analogue (measuring Lp) and integrated (measuring Leq) sound meter recordings of aircraft events 169 and 170 at site 3.



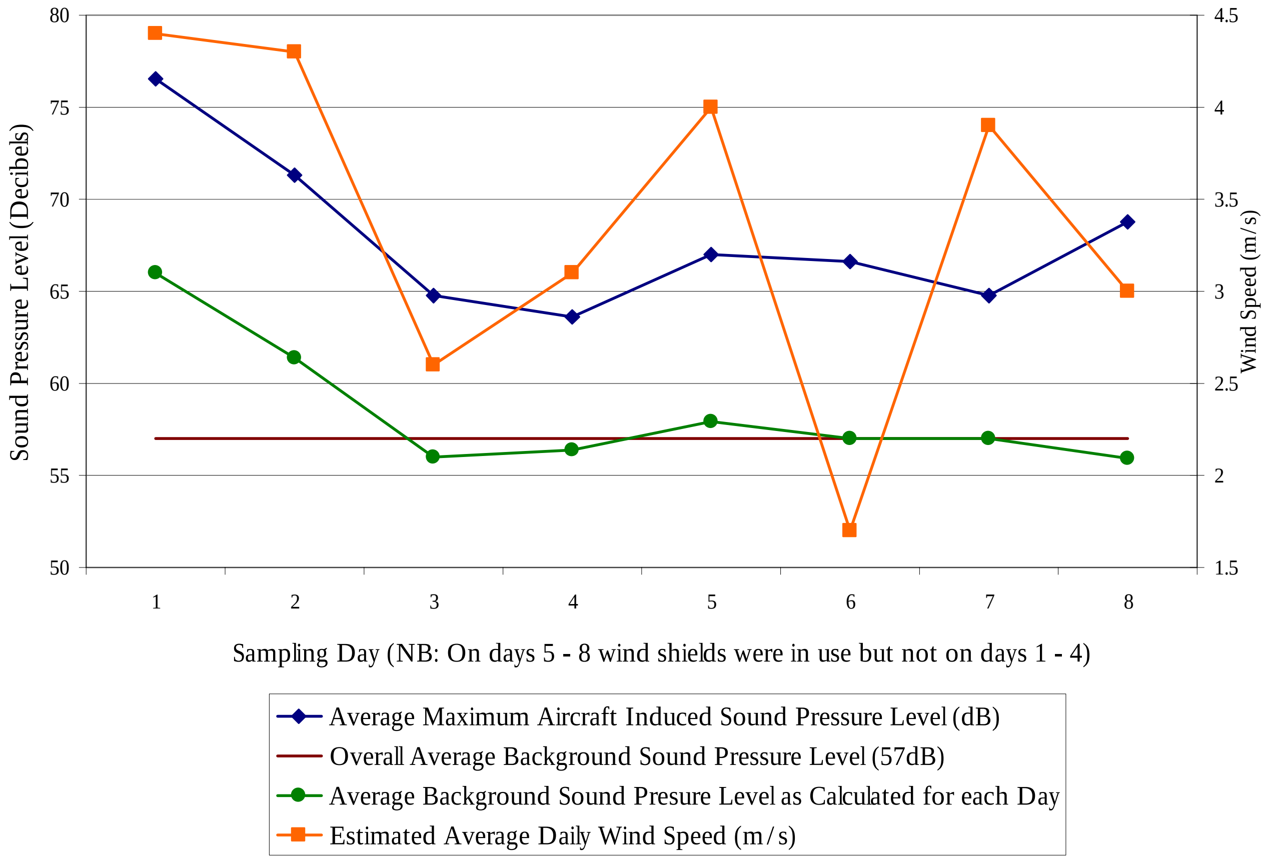
Appendix 3.3. Comparison between analogue (measuring Lp and absolute maximum) and integrated (measuring Leq) sound meter recordings at site 3 of a helicopter flyover and landing (event 181).

In appendix 3.1 both the trend of change and the peak decibel level reached by the two instruments are closely correlated. In appendix 3.2 the most notable difference between the curves is that the maximum peak reached by the analogue meter was not matched by the integrated meter suggesting that the sound level of 98dBA was maintained for an extremely short interval, resulting in an average over 5 seconds of

88.1dBA. In appendix 3.3 both the trend of change and the peak decibel level reached by the two instruments are well correlated.

Based on the assumption that the type 2 integrated sound meter used was a more accurate instrument than the analogue sound meters used, this data supports the use of Techcessories analogue sound meters for obtaining indicative results of sound levels at higher decibel levels (above 50dBA). However this analysis is complicated by the fact that the integrated meter used to give comparative and theoretically more accurate readings was itself well past its re-calibration date and when tested shown to be reading 1.8dBA lower than it should have been.

APPENDIX 4.0. Environmental Conditions.



Appendix 4.1. Relationship between wind speed and sound levels.

	Correlation Coefficients	
	Without windshields (days 1 - 4)	With windshields (days 5 - 8)
Wind Speed and Ave Max dB	0.91	-0.27
Wind Speed and Ave B/g dB	0.92	0.36

With d.f. = 2, results from days 1 - 4 are significant at $0.05 < p < 0.1$.
With d.f. = 2, results from days 5 - 8 are not significant ($p > 0.1$).

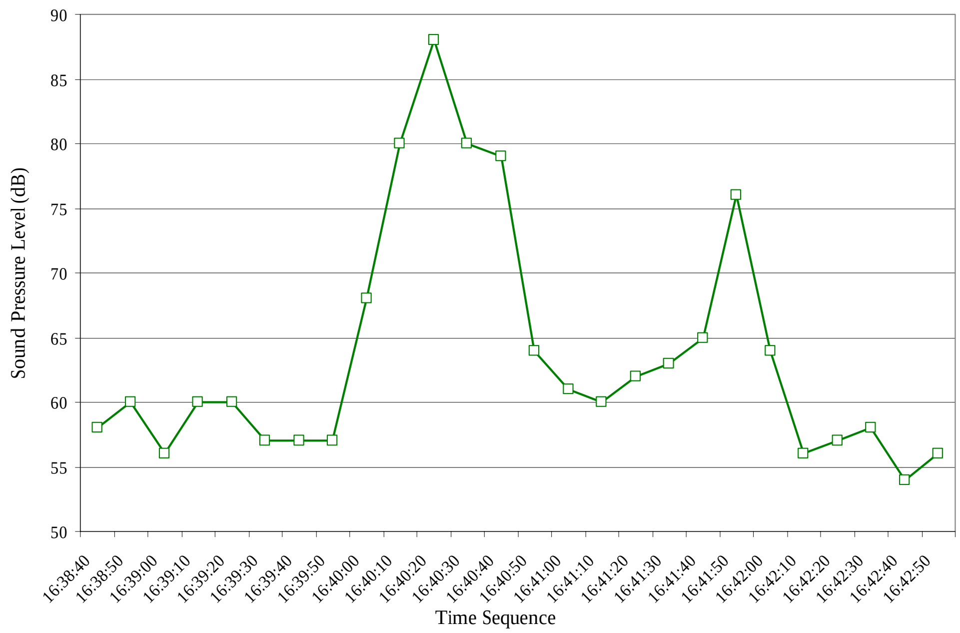
Appendix 4.2. Correlation coefficients between wind speed and sound levels. Assumes a normal distribution of x and y and a linear relationship between x and y.

Sampling Day	Average Daily Temperature (°C)	Average Daily Humidity (%)

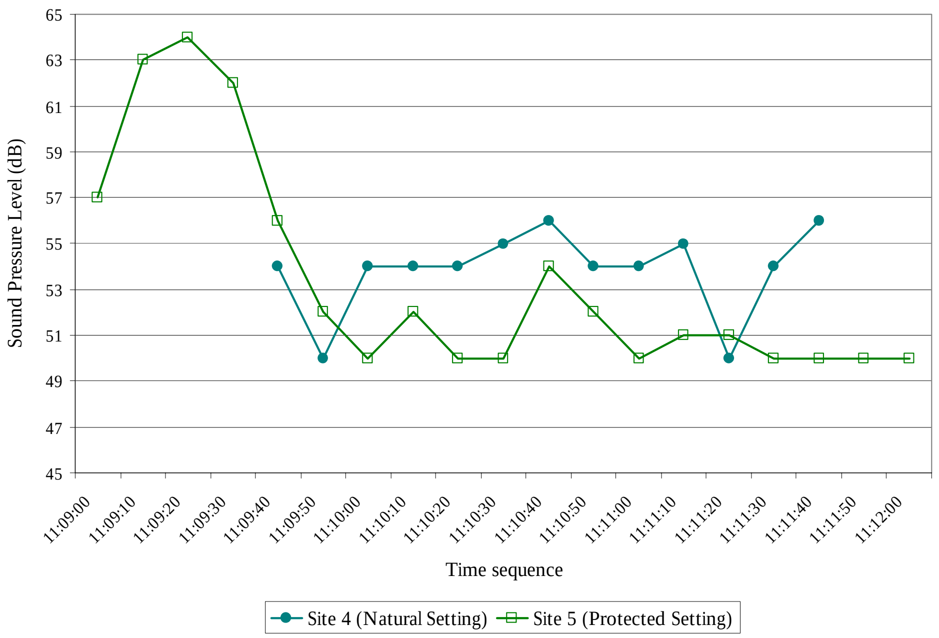
1	29.9	No measurement
2	27.1	No measurement
3	28.0	No measurement
4	No measurement	No measurement
5	26.7	81
6	27.3	77.3
7	27.7	84.1
8	26.0	89.5

Appendix 4.3. Temperature and humidity daily averages.

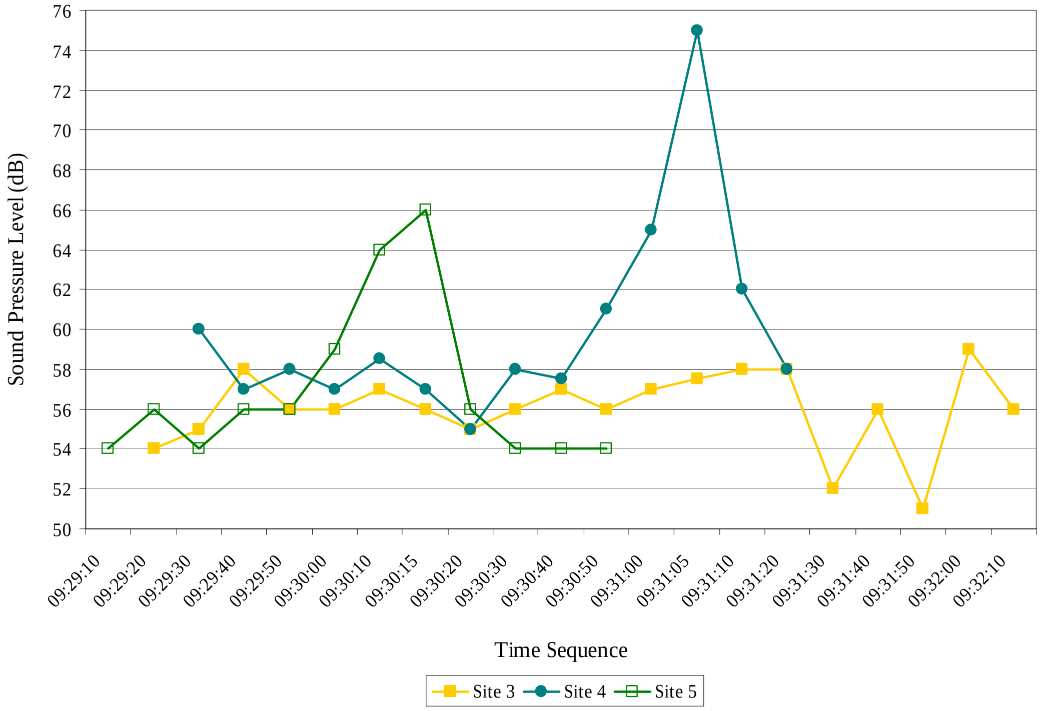
APPENDIX 5.0. Examples of Aircraft Events.



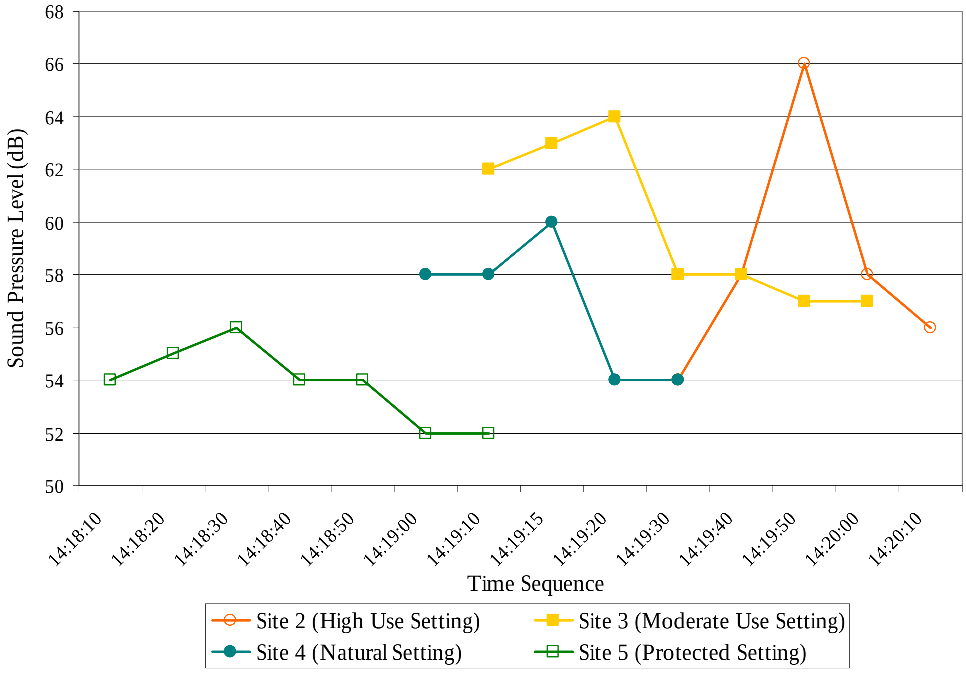
Appendix 5.1. Event 101 - Seaplane takeoff from in front of site 5. This aircraft was recorded only by site 5. It flew in a westerly direction over site 5.



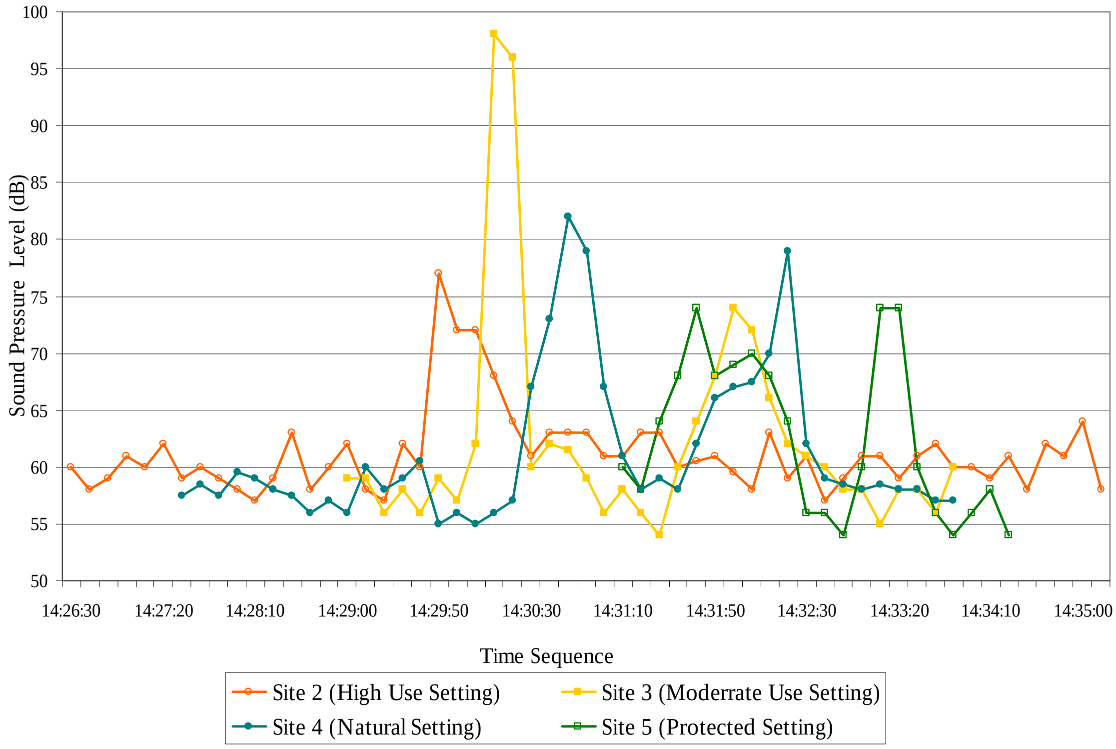
Appendix 5.2. Event 74 - Helicopter flyover at the northern end of Whitehaven beach. Event 74 registered above background sound levels at site 5 and was audible at site 4.



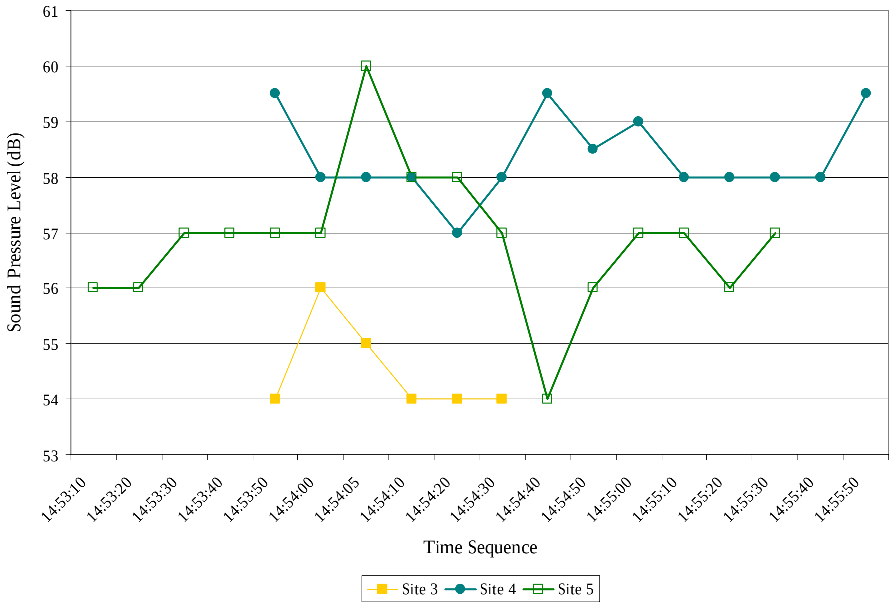
Appendix 5.3. Event 143 - Seaplane flyover from the north, landing close to site 4. This event was not noted or recorded by site 2 thus presumably site 2 was not aware of it.



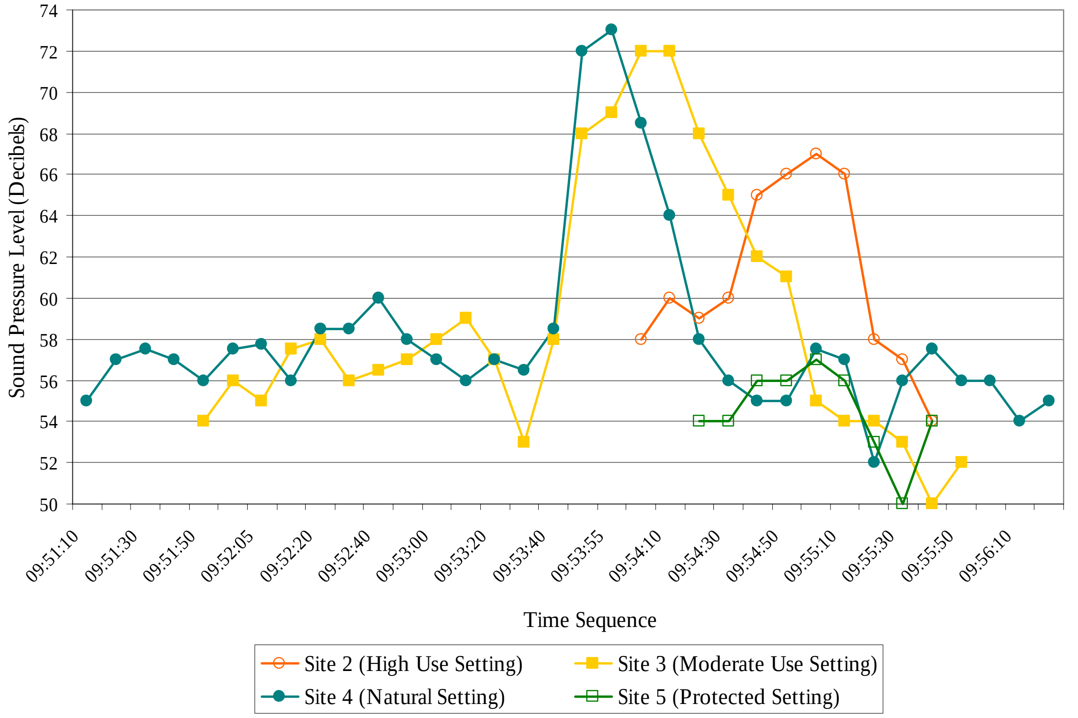
Appendix 5.4. Event 91 - Light aircraft (other than a seaplane) flyover from north to south.All sites recorded this event, registering a range of maximum sound levels for it.



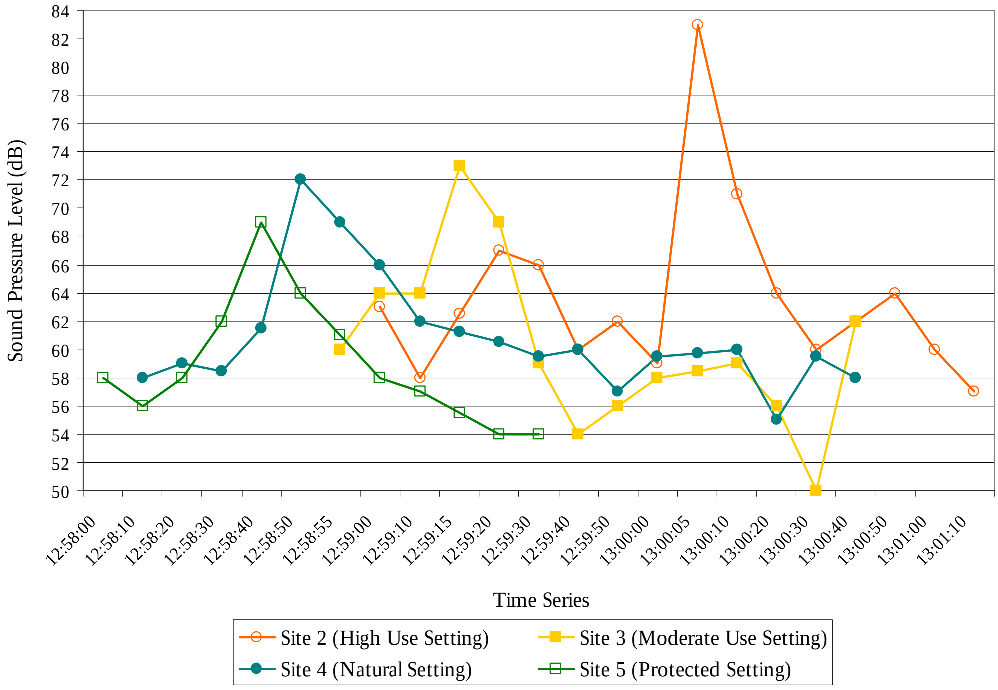
Appendix 5.5. Concurrent events 169, 170 (seaplane takeoffs) & 171 (seaplane landing). Event 169 took off from between sites 2 and 3 and flew toward the north impacting all sites. Event 170 took off from between sites 3 and 4 and also flew north. It was not noticed by site 2 at all. All sites other than 2 missed event 171 possibly partly due to the concurrent takeoff of 170 but also as it only flew over site 2 and landed close to site 2.



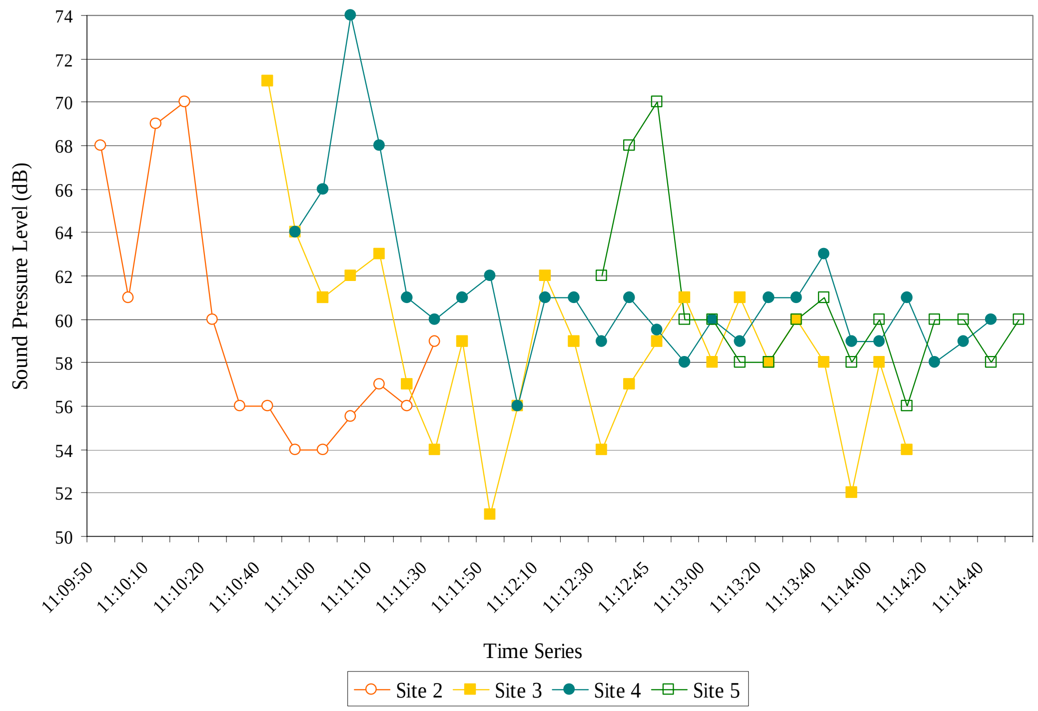
Appendix 5.6. Event 139 - Helicopter flyover in the vicinity of Hill Inlet. Event 139 registered above average background at sites 4 and 5 with a low peak of 60 dB.



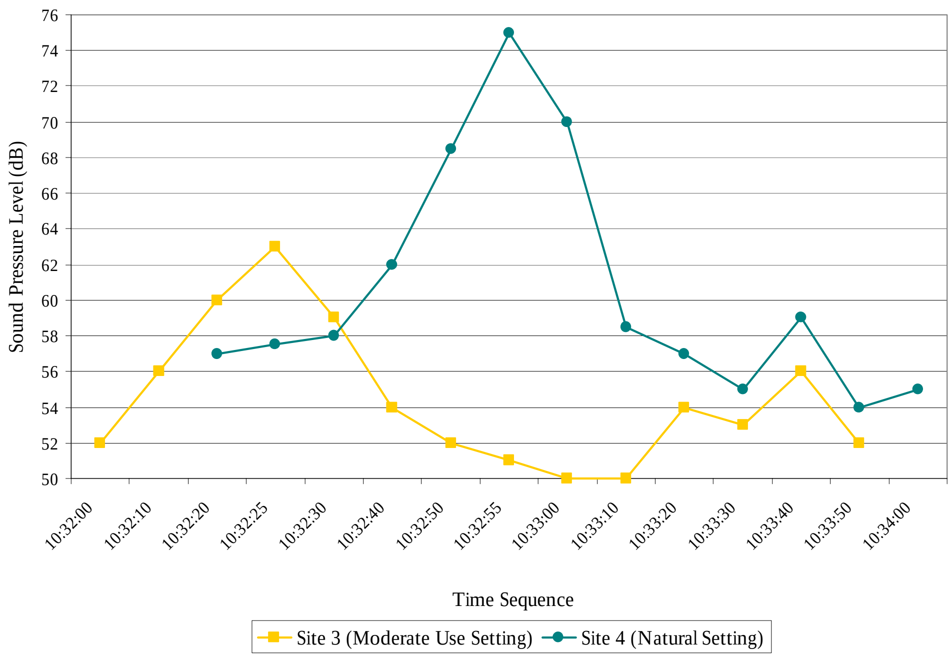
Appendix 5.7. Event 146 - Seaplane takeoff from between sites 3 and 4 and flyover toward the south. This event was first recorded by sites 3 and 4 and later by sites 2 and 5 (after takeoff).



Appendix 5.8. Event 164 - Seaplane flyover and landing close to site 2. Event 164 flew from north to south impacting all sites prior to landing close to site 2.

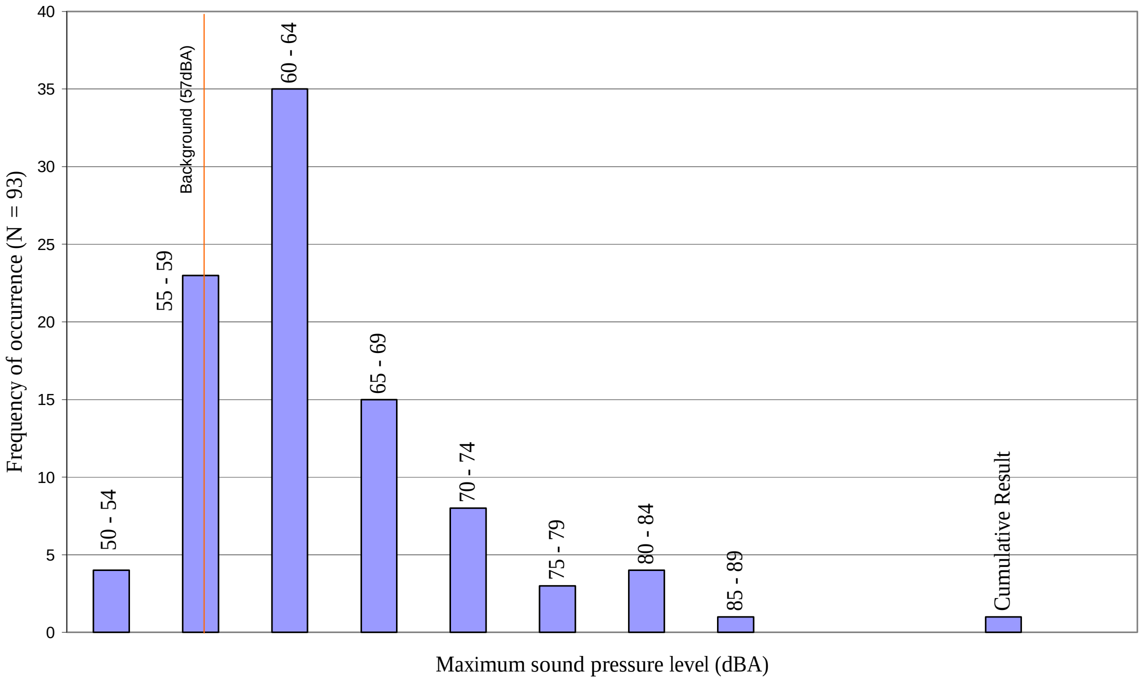


Appendix 5.9. Event 123 - Helicopter flyover from south to north. All sites started to record this event only when sound levels were well above average background levels. Thus, presumably sound levels increased suddenly.

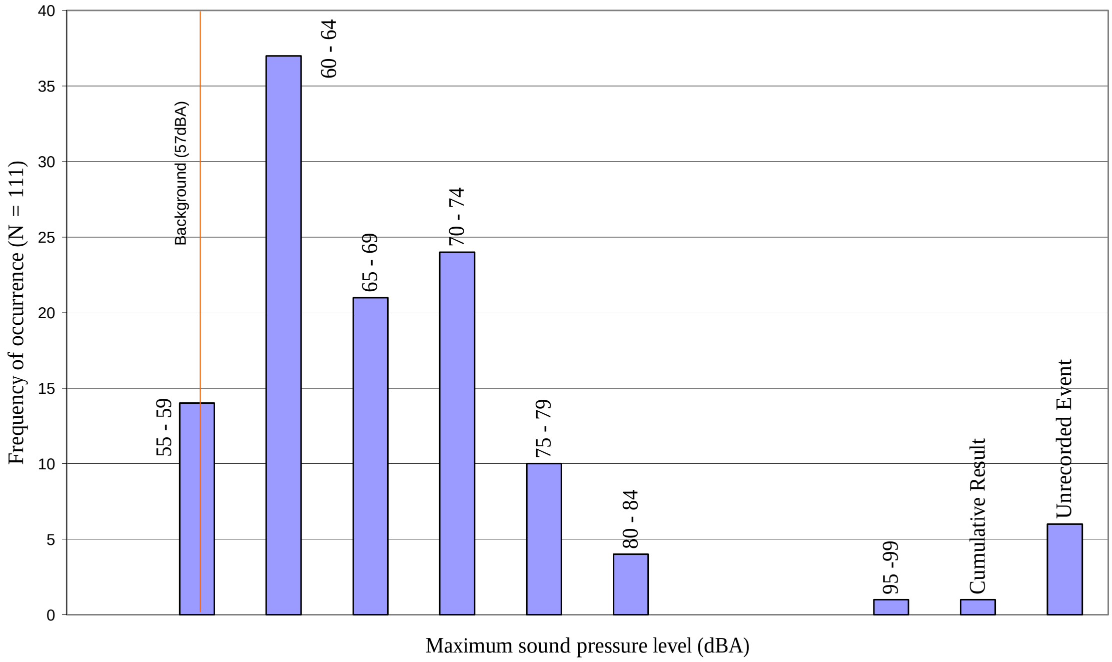


Appendix 5.10. Event 181 - Helicopter flyover / landing in the seasonal landing zone between sites 4 & 5.Event 181 probably approached from the land ward side of the beach thus impacting only the middle of the beach (sites 3 and 4).

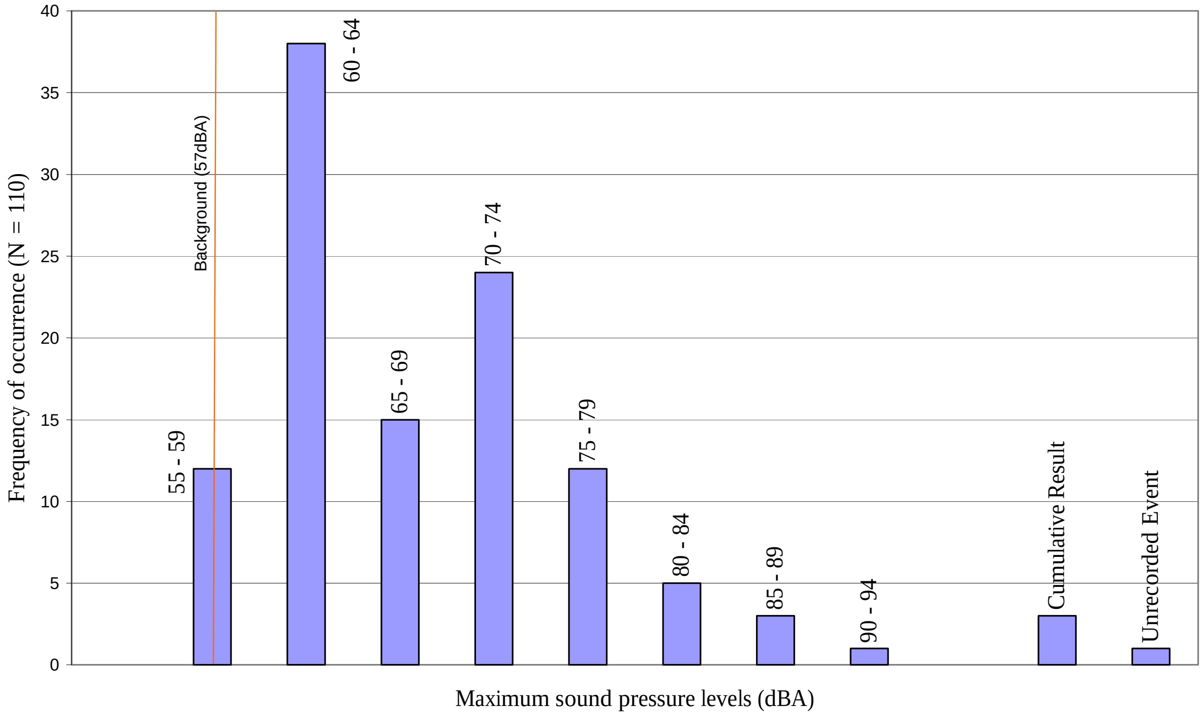
APPENDIX 6.0. Further Results – Aircraft Sound.



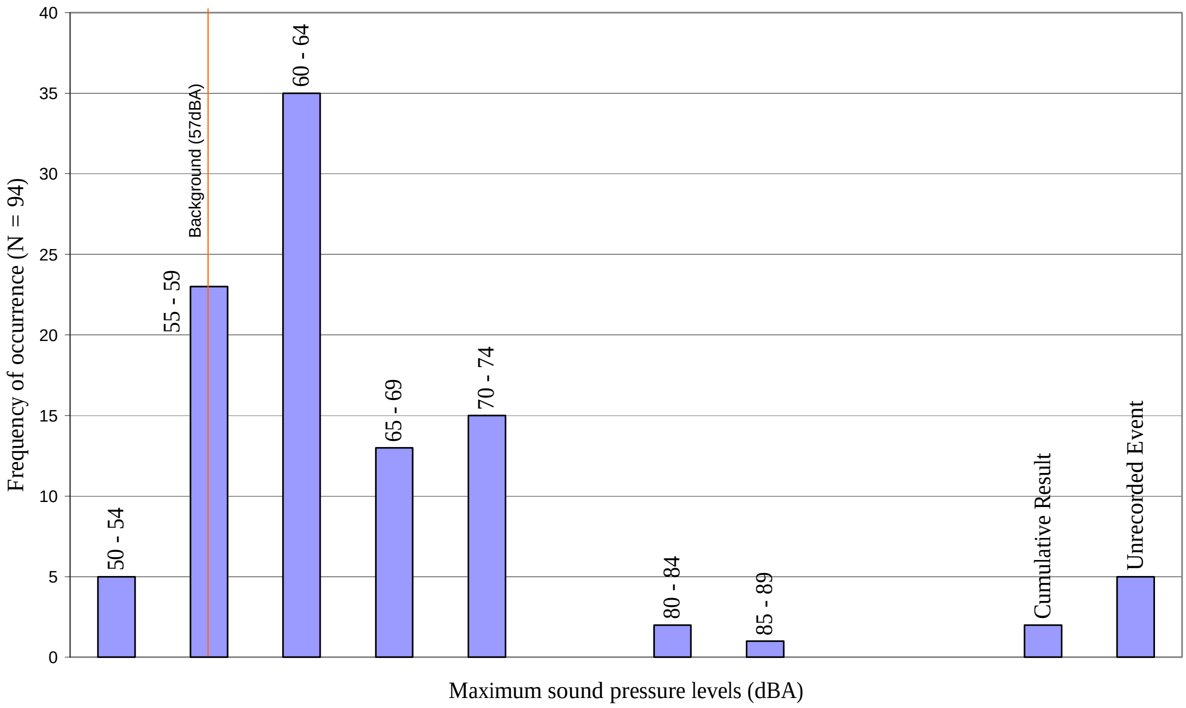
Appendix 6.1. Frequency of occurrence of Lmax aircraft induced sound levels at site 2.



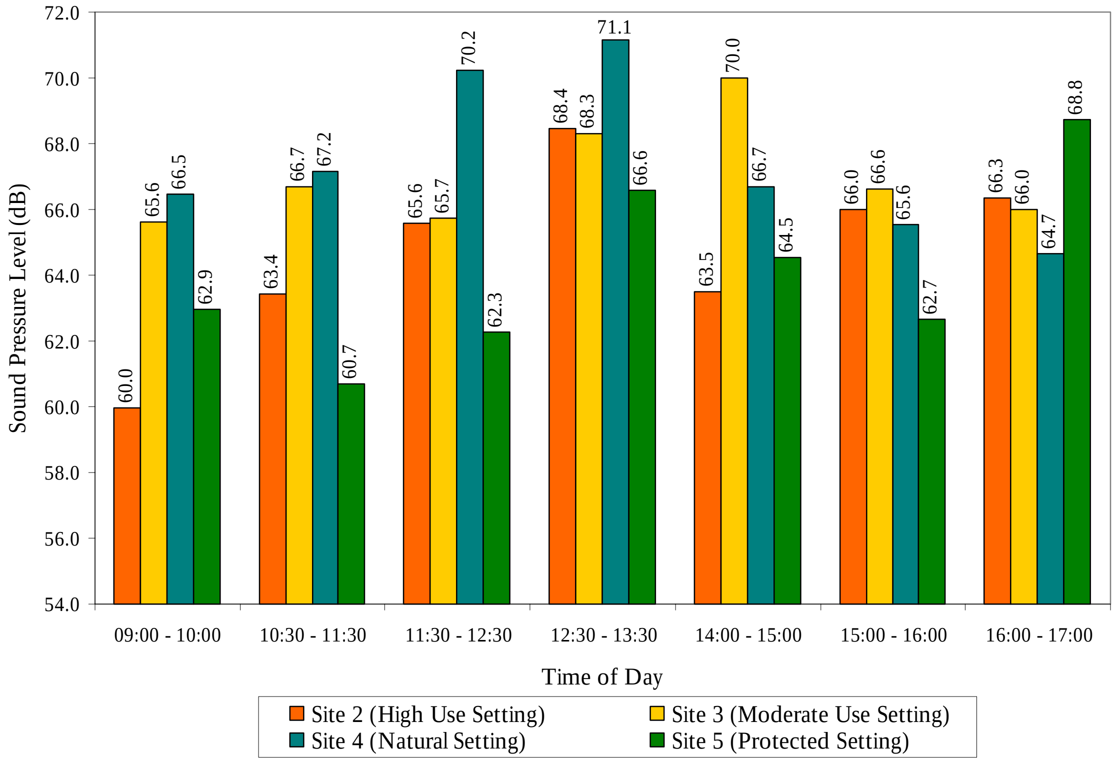
Appendix 6.2. Frequency of occurrence of aircraft induced Lmax sound levels at site 3.



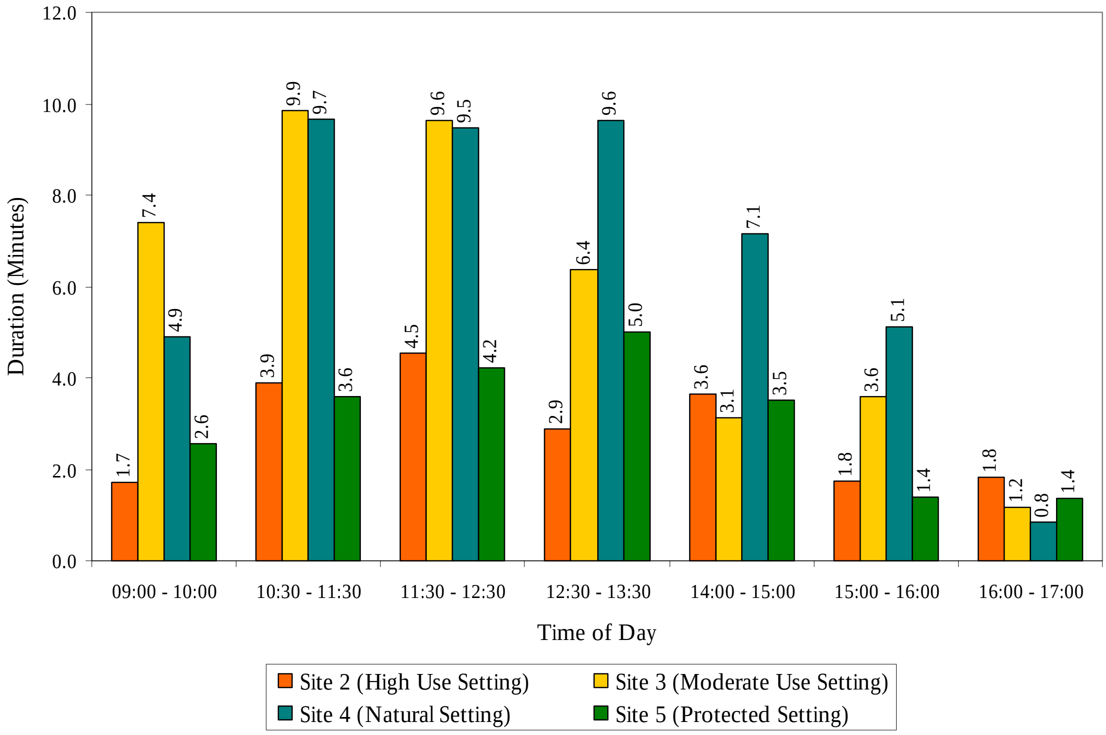
Appendix 6.3. Frequency of occurrence of Lmax aircraft induced sound levels at site 4.



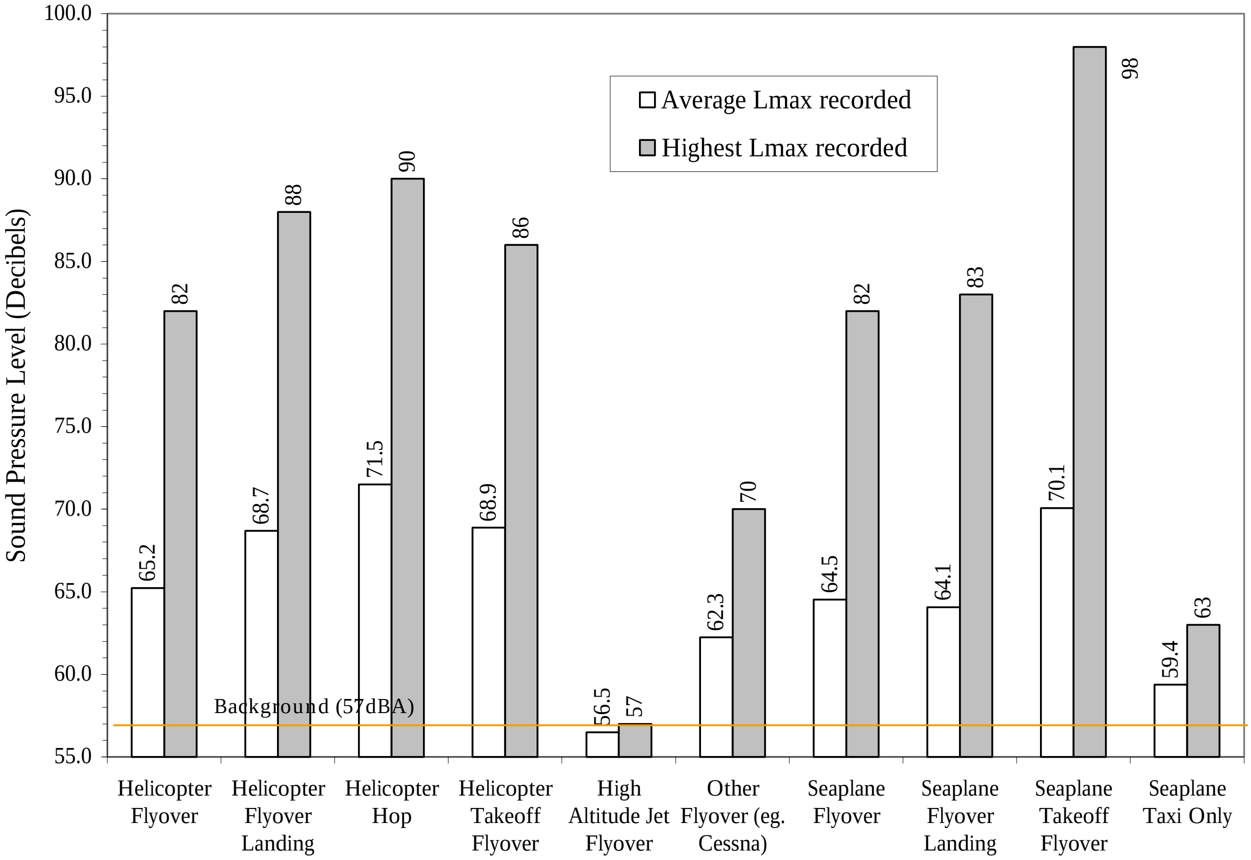
Appendix 6.4. Frequency of occurrence of maximum aircraft induced sound levels at site 5.



Appendix 6.5. Average aircraft maximum decibel levels relative to site and time of day (based on data collected on days 3 - 8).



Appendix 6.6. Average hourly duration of aircraft sound relative to site and time of day (based on data collected on days 3 - 8).



Appendix 6.7. Average and absolute Lmax relative to aircraft event type (based on data collected on days 3 - 8 of trips 1 & 2).

When results measured for helicopter and seaplane 'takeoff flyovers' recorded during break periods are included in the calculation, the overall averages for these event types increase to 70.1 and 71.1dBA respectively.

Due to the use of broader classifications of event types, and the averaging of readings based on recordings made at all sites recording the same event (therefore over distances up to 6 km), there is a less specific association between event type and sound level experienced than in figure 4.9, while averages are dampened. Data for appendix 6.7 is based on a larger data set than that for figure 4.9, however, again not all event types occurred with equal frequency. Thus for example, although seaplanes are well represented, helicopters are proportionally under represented.

APPENDIX 7.0. Factors of Sound Measurement.

When measuring sound and noise, the relevant measurement standards, the weighting network to be used, the acoustical metric(s) to be used, and the sampling period are all core factors which must be taken into consideration. When measuring aircraft sound levels an understanding of the effect of altitude is also relevant.

Appendix 7.1. Measurement Standards

Sound level meters and techniques of sound measurement must comply with international or national standards (Maekawa and Lord 1994). Australian Standards 1055, 1259 and 2659 are relevant to this study. Sound level meters meeting Australian standards are classed as either type 0, 1, 2 or 3, each being designed for slightly different purposes. Other types of sound meters are those which do not comply with the standards but which may be satisfactory for particular applications. Types 0 and 1 are typically used for technical sound studies with direct legal implications although they must meet rigorous specifications if used in the field (Standards Australia 1988).

Australian standards on noise measurement do not specifically address the measurement of aircraft noise in National Parks. Notably, standard sound level meters used in community noise studies, will not accurately measure below 20 to 25 decibels. Thus special "low-noise" instruments are required for studies where it is imperative to establish the level of extreme quiet (Horonjeff et al. 1993; US National Park Service 1994).

Appendix 7.2. Weighting Networks

The type of weighting curve used in measuring sound is important in determining the accuracy of the result as a measure of the impact of the sound on those hearing it. The frequency of sound determines the ability of the human auditory system to detect it. As a sound of constant sound pressure level decreases in frequency from about 1 kHz or increases in frequency from about 5kHz, it's loudness decreases. Therefore, in order to measure what is actually being heard by humans, measurement of sound pressure level is adjusted to account for the relative loudness of the frequency through the use of weighting networks (A, B and C) in sound level meters. Networks are based on approximate equal-loudness contours rather than the hearing threshold curve (Boeker and van Grondelle 1995; Standards Australia 1988).

The A weighted network is considered to most accurately represent human perception of noise (Maekawa and Lord 1994; Boeker and van Grondelle 1995; Berglund et al. 1996) and to date has been the most commonly used network for measuring sound levels of aircraft in National Parks. However, it underestimates the importance of low frequency sound. Therefore, noise which contains a substantial frequency component below about 100 hertz has its loudness underestimated by the equivalent of 9dB within the range of 52 - 70dB(A). Regardless of the frequency, for sounds exceeding a sound pressure level of 60dB, the reliability of the A-weighting decreases (Berglund et al. 1996). Methods of better accounting for aircraft noise, which has a significant low frequency component, are under development (Maekawa and Lord 1994; Berglund et al. 1996).

Appendix 7.3. Metrics Used

Metrics commonly used to describe aircraft overflights and background sound levels in national parks are:

- Lmax (dBA): The maximum A-weighted sound level reached;
- Leq (dBA): The equivalent A-weighted sound level (the logarithmic sum of sound exposure levels (SELs) over a specified time period);
- Ldn: The day-night average sound level. A 24 hour energy average A-weighted sound level with 10 dB added to night (20:00 - 07:00 hours) measurements.
- Onset rate (dB/second): Representing the maximum rate of increase in A-weighted sound level;
- Duration of aircraft sound levels above background sound levels;
- Percentage chance of detection by attentive listeners on the ground;
- The audibility of the aircraft (dB) (The audible portion of the total sound exposure);
- The aircraft's audible duration (seconds).
  (Brown 1986; US National Parks Service 1992; Anderson and Horonjeff 1992).

Appendix 7.4. Sampling Period

DeVor et al. (1979), Schomer and DeVor (1981) and Schomer et al. (1983) address the issue of sampling strategies for establishing the yearly Ldn close to airports. Noise levels in the vicinity of airports were found to be correlated serially in time, thus, they concluded that in order to estimate the yearly Ldn within +2 to -3 dB of the true value and with a 95% confidence level, sampling needs to be done in one of the following ways:

1. Fourteen days of totally random sampling;
2. Three to four weeks of quasi-random sampling taken one week at a time, ensuring that no periods are consecutive; or
3. At least thirty days of continuous sampling.

Bowlby et al. (1990) used the second sampling strategy for their study of aircraft noise in Grand Teton National Park in the vicinity of Jackson Hole airport. They sampled four week long periods as a function of season. To my knowledge there have not yet been any studies which specifically address the issue of establishing sampling strategies for aircraft overflights in protected areas.

Appendix 7.5. The Effect of Altitude

Anderson and Horonjeff (1992) discuss the effects of aircraft altitude upon sound levels on the ground. They discuss the causes of sound levels decreasing with distance and cite the most important of these as being: spherical divergence; atmospheric absorption; ground attenuation; shadow effects; attenuation due to topography and heavily wooded areas; and the acoustical metric being used to describe the overflight.

When the flight path is directly or nearly overhead, sound levels experienced by a listener on the ground decrease as aircraft height increases. Lmax, Leq, Ldn and Onset rate metrics experience diminishing reductions in value with increasing height. As a general rule, reductions of 4 - 10dB in sound exposure require a doubling of the distance between the aircraft and the ground. Comparatively, 'audibility' acoustical descriptors (such as percent of time audible) depend more on background sound levels. Subsequently, sound levels initially decrease following the same trend as the descriptors, Lmax, Leq, Ldn and Onset rate, but then rapidly decrease at higher altitudes due to masking of aircraft sound by background sound levels. This trend is characteristic of all aircraft overflights, however, the height at which an overflight begins its rapid reduction in audibility is highly variable and dependent on aircraft type, aircraft speed and background sound levels. Thus, the type of metric used to monitor sound levels affects the value placed on increasing altitude as a noise mitigation measure.

When flight paths are lateral to the listener, the situation becomes more complex as at low elevation angles, aircraft sound may be attenuated by acoustically soft ground, intervening hills and wooded areas. Thus, increasing aircraft height results in an increase of sound level once the aircraft gets to a height beyond the influence of the ground. Subsequently however, sound level decreases with increasing height in the same manner as when an aircraft is directly or nearly overhead.

APPENDIX 8.0. Glossary

This report contains the following technical terms:

Ambient sound: The all encompassing sound at a location (Standards Australia 1988).

Amenity: The pleasantness of a place, features and circumstances agreeable to mind, feelings and senses of the users. This definition includes not only the aesthetics but also matters such as ecological integrity, noise, the proximity of other people, their activities, vessels and structures (Adami and Jennings 1995).

Anthropogenic: Produced or caused by man (Lawrence 1995).

A-weighted network: A frequency-equalising function intended to approximate the sensitivity of human hearing to sounds of moderate sound pressure level (US Forest Service 1992).

Background sound: The ambient sound in the absence of the sound under investigation (Standards Australia 1988). In this study as all anthropogenic sound sources were under investigation, thus 'background sound' is equivalent to 'natural sound' and the terms are used interchangeably.

dBA: The A-weighted sound level measured in decibels.

Decibel (dB): The most commonly used unit of sound measurement. The decibel scale is a logarithmic scale, derived from the Pascal scale and based on sound pressure levels (the physical correlate of loudness). The threshold of human hearing is at 20 micropascals or 0dB. A change of 20dB corresponds to a ten-fold increase in micropascals. Thus, 20 dB is equivalent to 200 micropascals. However, the decibel scale gives a better approximation of the perception of loudness than the Pascal scale, 1dB indicates the same fractional change in sound pressure at all levels and is about the smallest change that the average person can reliably detect. A 6dB increase corresponds to a doubling of the sound pressure, however a 10dB increase is necessary for the sound to be perceived as being twice as loud (Standards Australia 1988; Maekawa et al. 1994; Boeker and van Grondelle 1995).

Event (applicable to aircraft and watercraft): An individual aircraft / watercraft visitation for as long as it is continuously within visual and/or audible range. Aircraft event classifications used in the main analysis are: Flyover only, flyover and landing, takeoff and flyover.

Ldn: The day-night average sound level. A 24-hour energy average A-weighted sound level with 10dB added to night (2000-0700 hours) measurements (US Forest Service 1992).

Leq: The equivalent sound level measured in decibels (the logarithmic sum of sound exposure levels over a specified time period) (US Forest Service 1992).

Lmax: The maximum sound level reached measured in decibels (Anderson et al. 1992).

Lp: The sound pressure level taken at an instant (Standards Australia 1997).

Natural quiet: The natural ambient sound condition occurring in a park unit (Lee 1994).

Natural sound: Natural ambient sound conditions. In this study natural sound is equivalent to background sound and the terms are used interchangeably.

Noise: unwanted sound (Maekawa and Lord, 1994; Bell et al. 1996; Berglund et al. 1996) or "sound having amplitude, frequency content, situational, or temporal qualities that are inappropriate to the particular setting-" (US Forest Service 1992, p2-1).

Noise is recognised as having both a physical and a psychological component. The physical component is set while, the psychological component (the degree of annoyance) depends on the listener and their physiological and psychological state as well as the frequency and time varying pattern of the sound. Low frequency (particularly anthropogenic sources) and impulse sounds are thought to result in higher levels of annoyance. Sources of low frequency sound include aircraft, wind and waves. Sources of impulse sound include artillery and sonic booms. (Berglund et al. 1975; Hall et al. 1981; Maekawa and Lord 1994; Bell et al. 1996; Berglund et al. 1996).

Onset Rate: The slope of increase in sound level with time (expressed as dB/s) (US Forest Service 1992).

Percent of time audible: The proportion of time during a period of recording that aircraft are audible to attentive listeners on the ground (Anderson et al. 1992).

Recreation opportunity: A chance for a person to participate in a specific recreational activity in a specific setting in order to realise a predictable recreational experience (Stankey and Wood, 1982).

Recreation opportunity spectrum (ROS): A method of recreation planning used to provide for a variety of recreational user tastes. It does so by combining social, managerial and environmental factors in a range of ways to produce a spectrum of recreation opportunity settings, ranging from natural, undeveloped and low-population density settings to unnatural, developed and high population dense settings. The ROS is best applied on a regional scale (Manning 1986).