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).

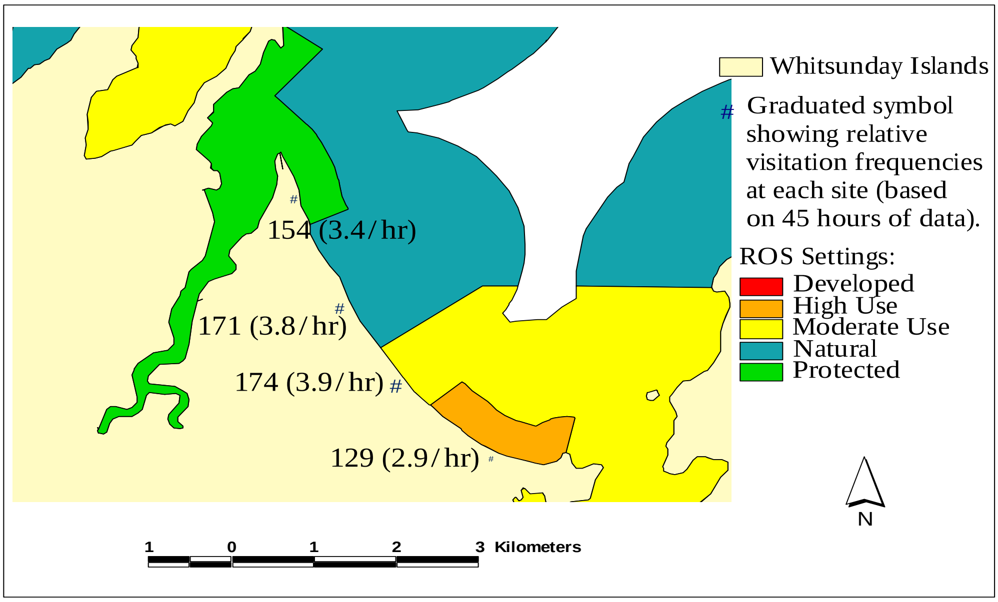

Figure 4.1. Total number of aircraft events relative to data collection site.

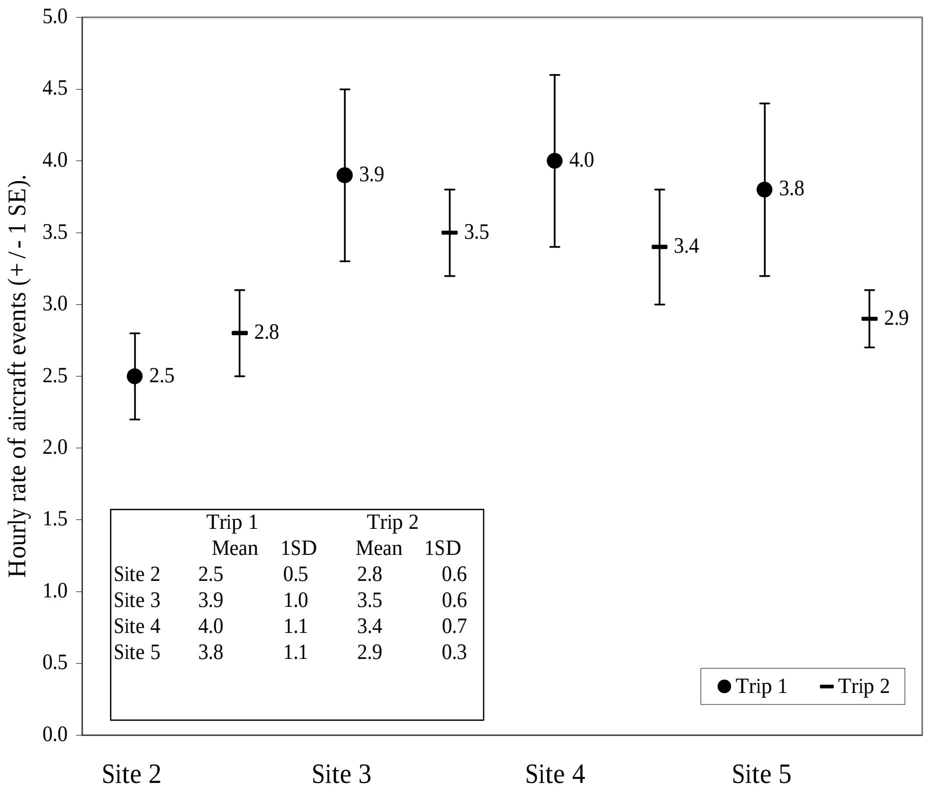

Figure 4.2. Hourly rate of aircraft events at each site on each trip +/- 1 SE.

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.

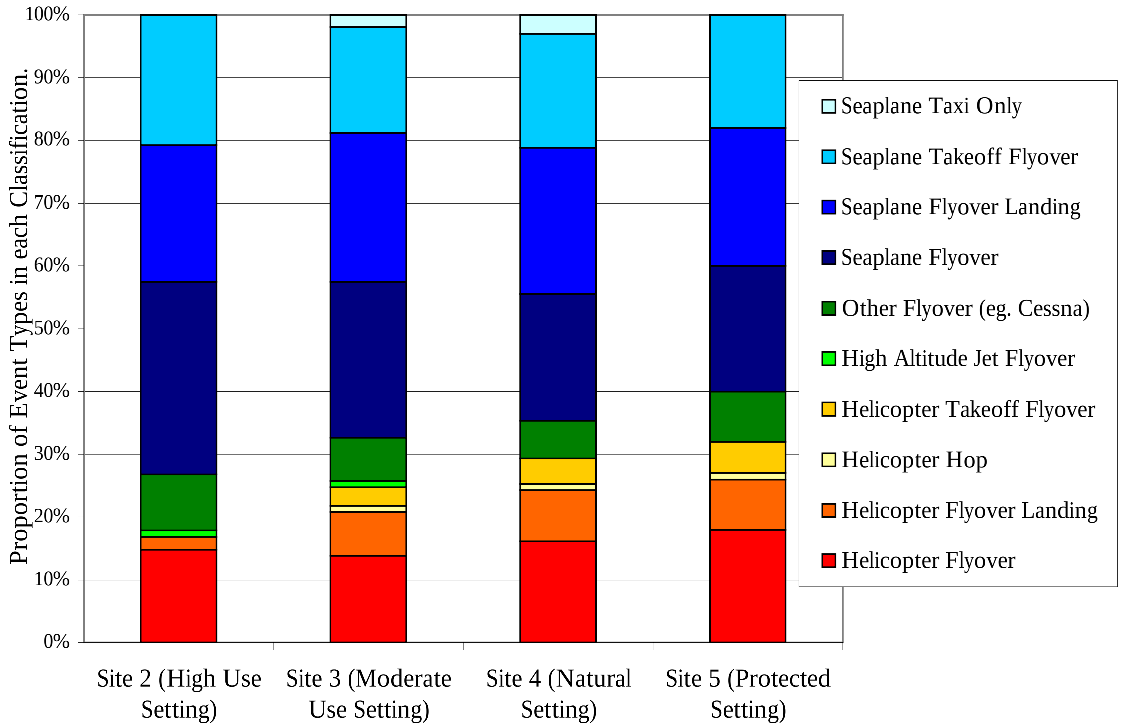

Figure 4.3. Proportion of event types experienced at each site.

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.

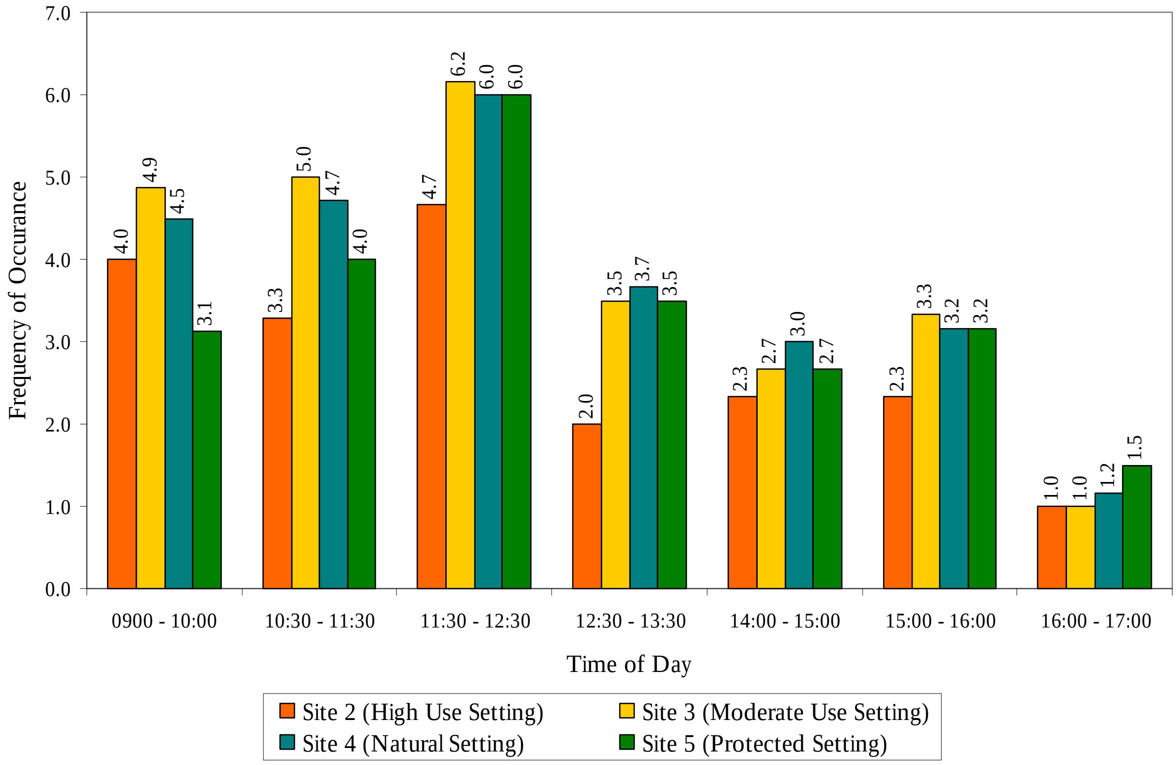

Figure 4.4. Average hourly number of aircraft events at each site.

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.

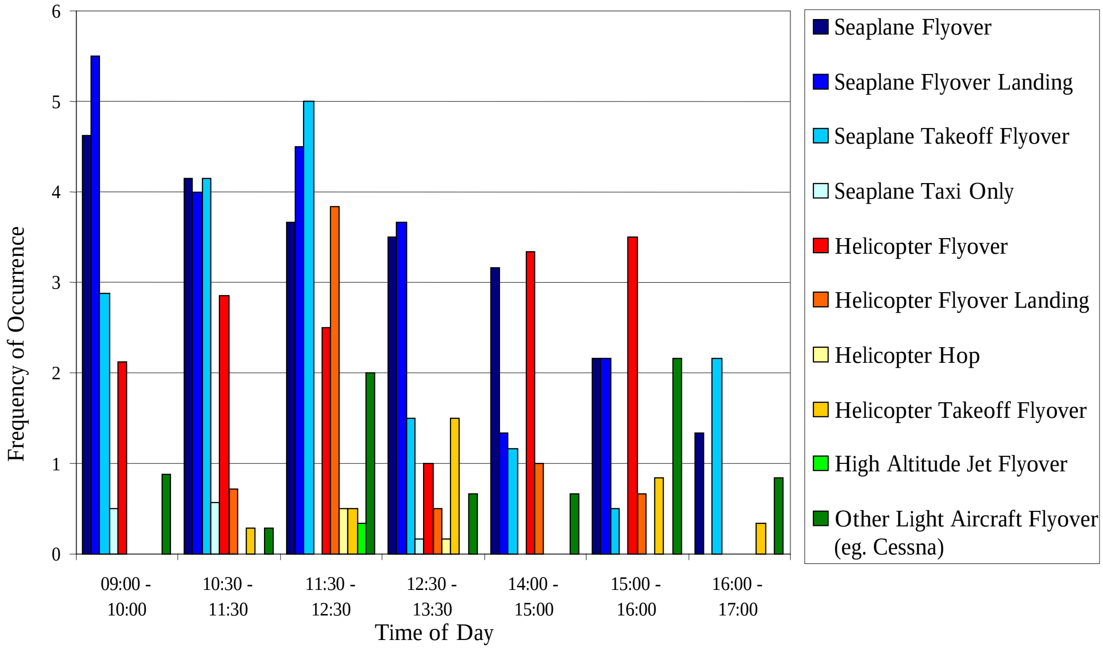

Figure 4.5. Average hourly number of different types of aircraft events.

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.

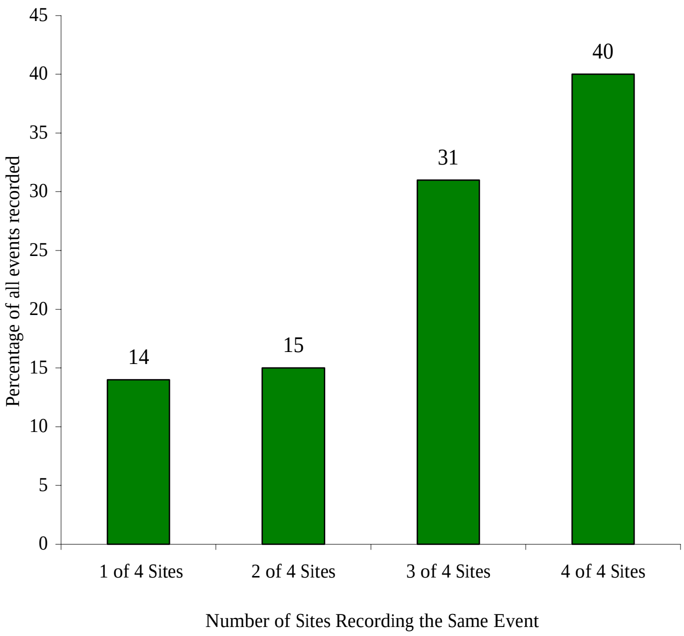

Figure 4.6. Proportion of aircraft events affecting 1, 2, 3 or 4 sites.

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.

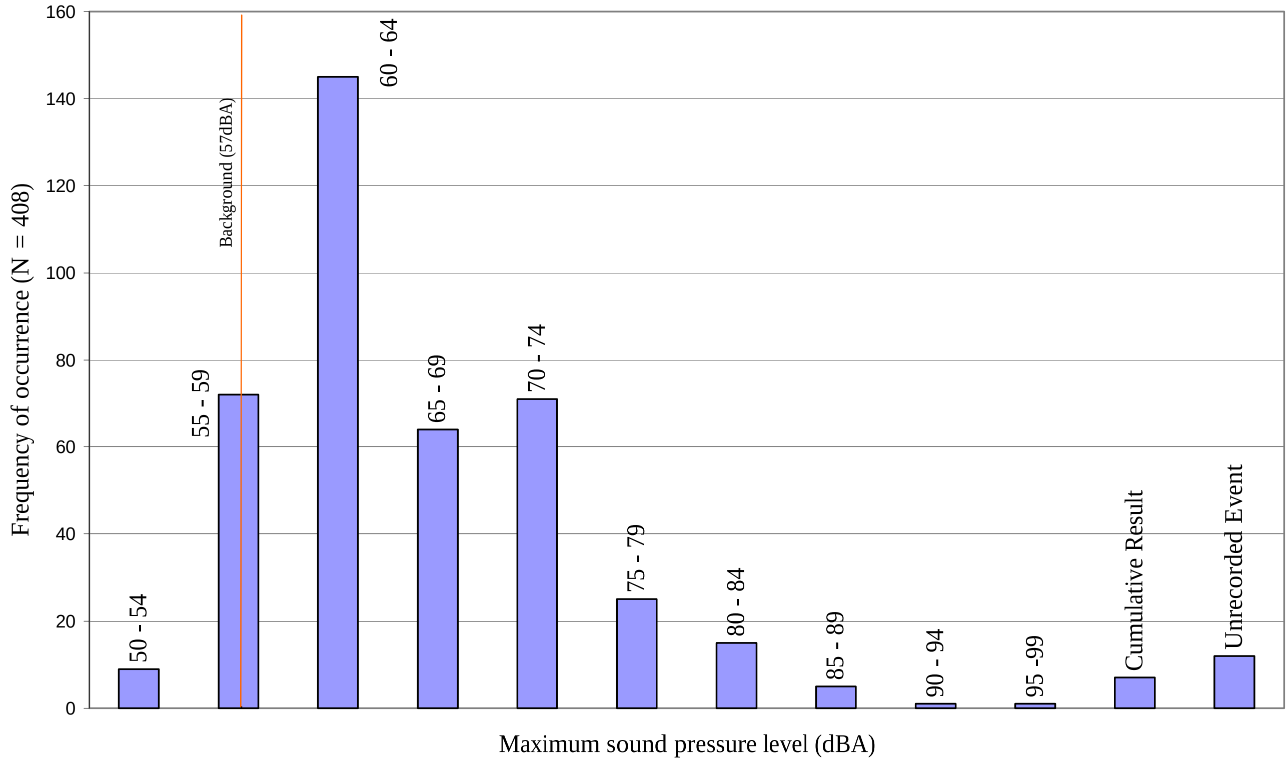

Figure 4.7. Distribution of maximum sound pressure levels over all sites.

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

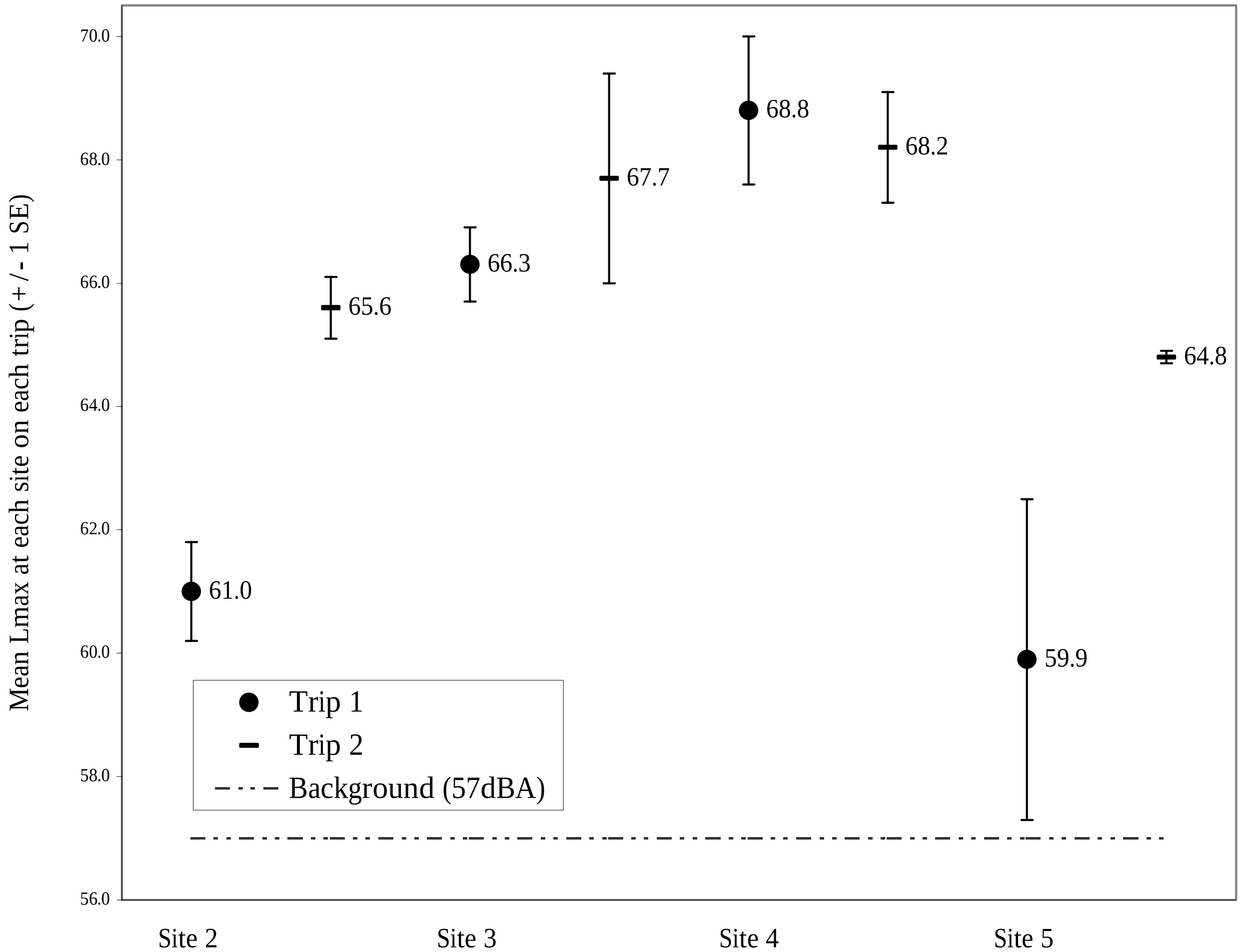

Figure 4.8. Mean aircraft Lmax recorded at each site on each trip (Error bars = +/- 1 SE). Results for trip 1 are calculated from daily averages on days 3 & 4 (due to wind induced noise on days 1 & 2). Results for trip 2 are calculated from daily averages on days 5 - 8.

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.

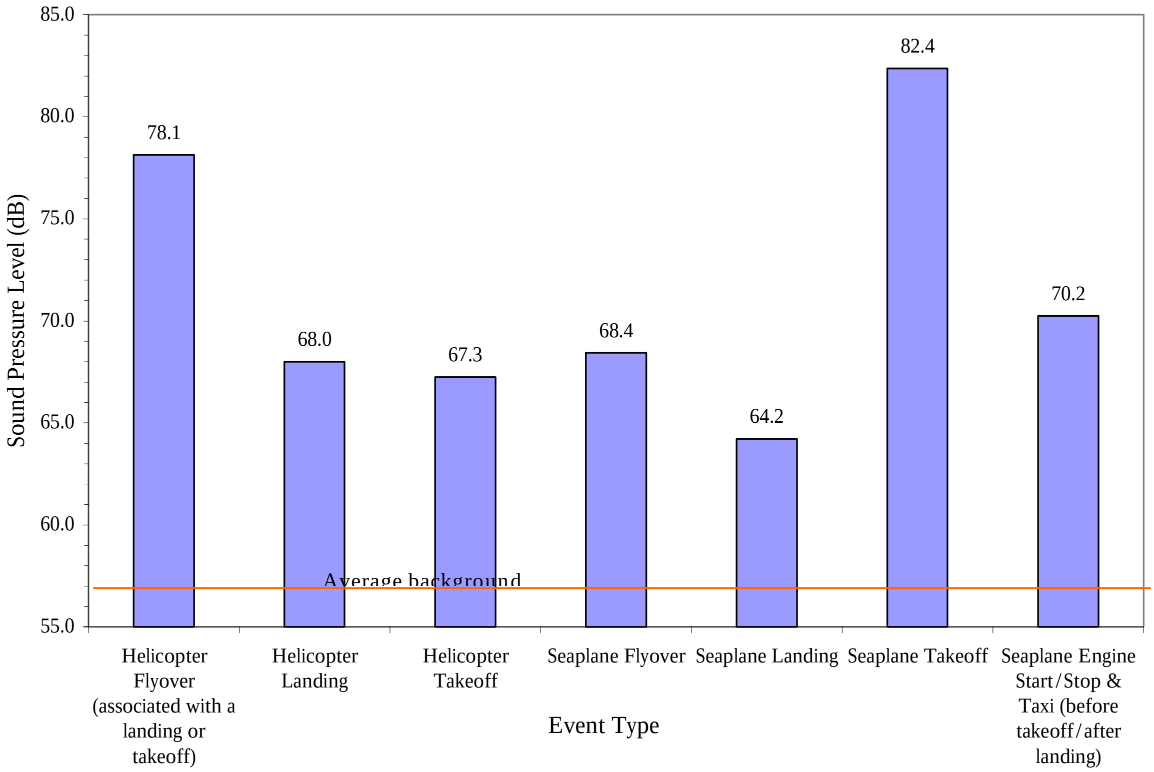

Figure 4.9. Average maximum sound pressure levels relative to event type. Results are compared with the average background sound level (57dBA) established on trips 1 and 2.

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.

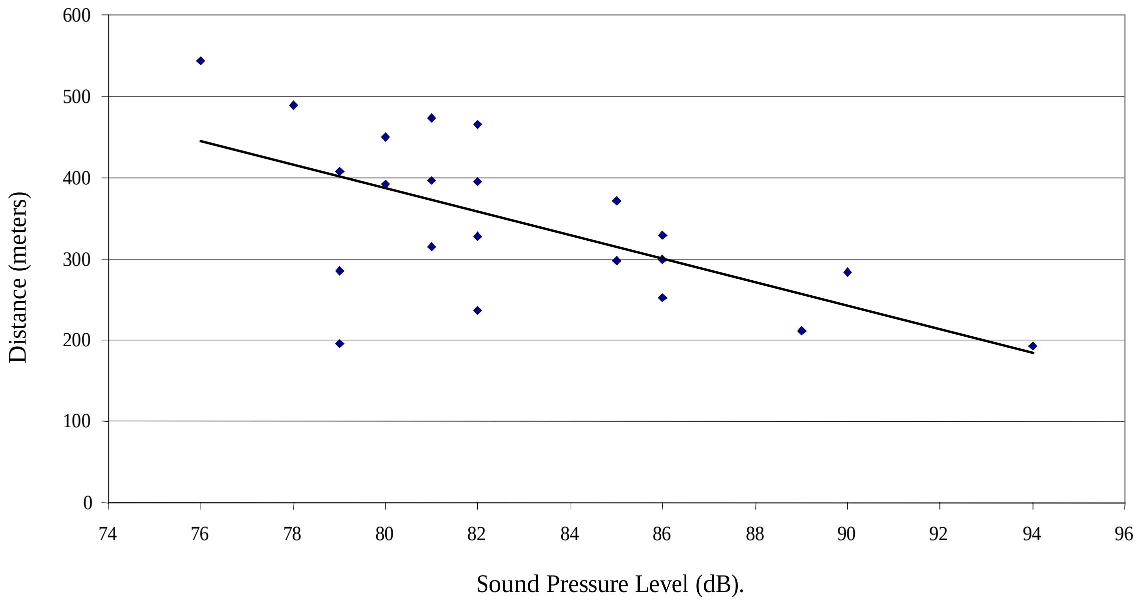

Figure 4.10. Relationship between distance and Lmax levels during seaplane takeoffs.

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

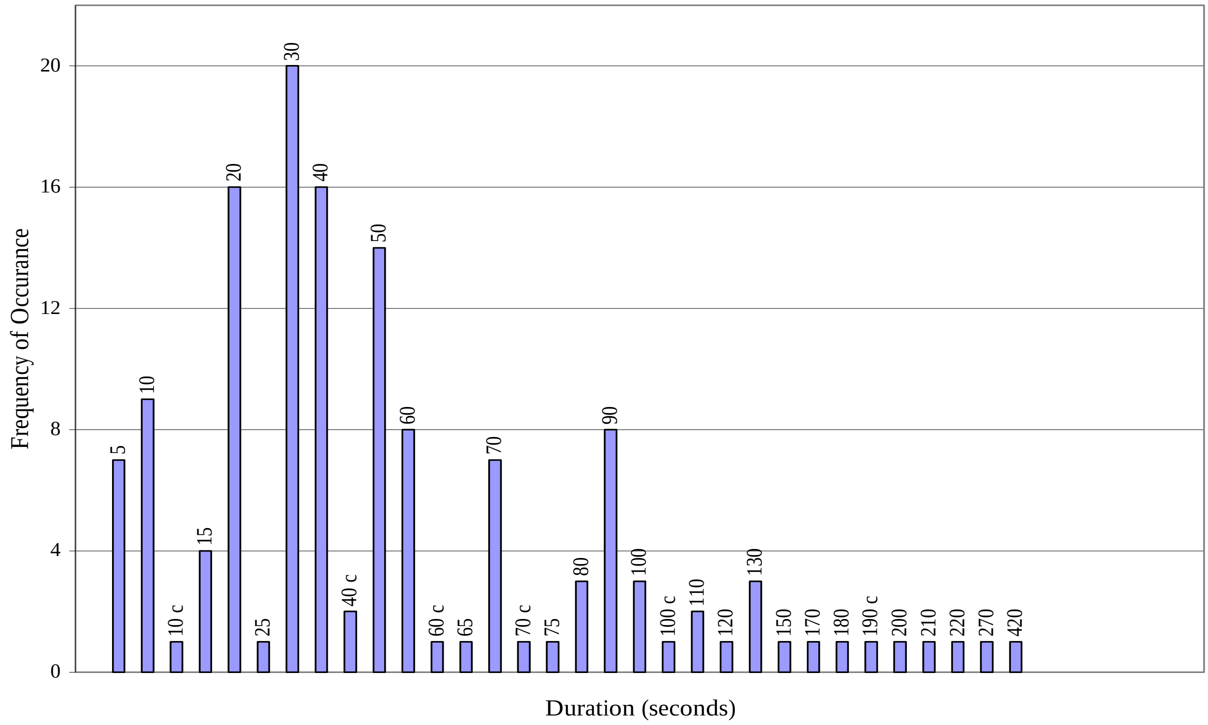

Figure 4.11. Durations of aircraft events in seconds. (Figures followed by a 'c' indicate that the result was cumulative, in other words, based on several aircraft events occurring simultaneously).

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.

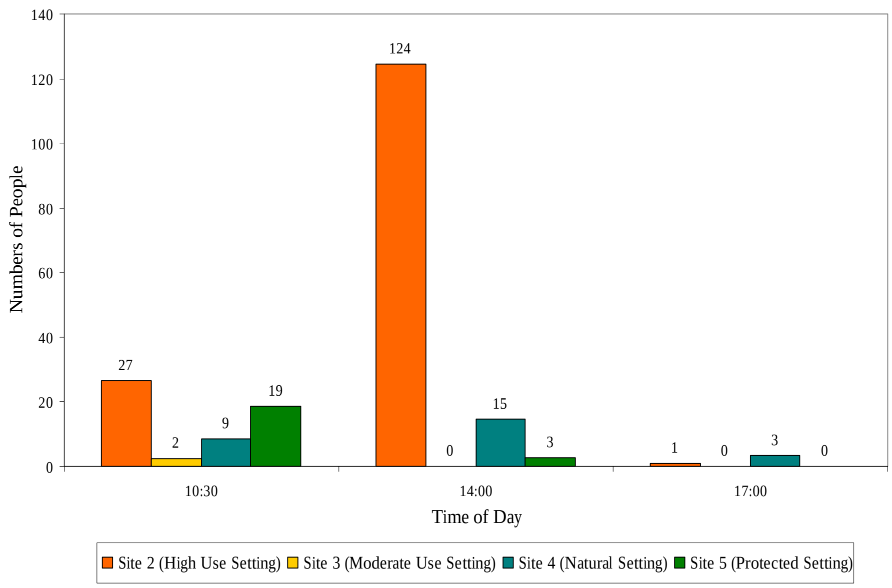

Figure 4.12. Average number of people within each setting at three set times of day. Based on data collected over days 5, 6 and 7.

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.

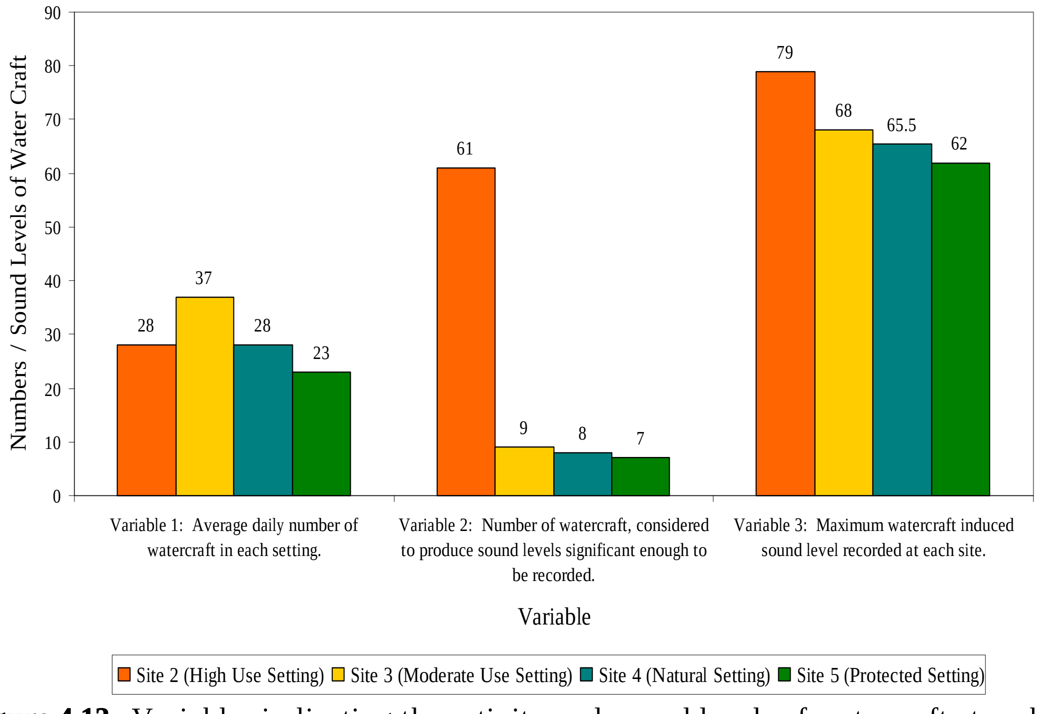

Figure 4.13. Variables indicating the activity and sound levels of watercraft at each site Variable 1 is based on 6 full days of data collection (days 1 -3, 5 -7). Variables 2 & 3 are based on data collected on days 3-8.

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			

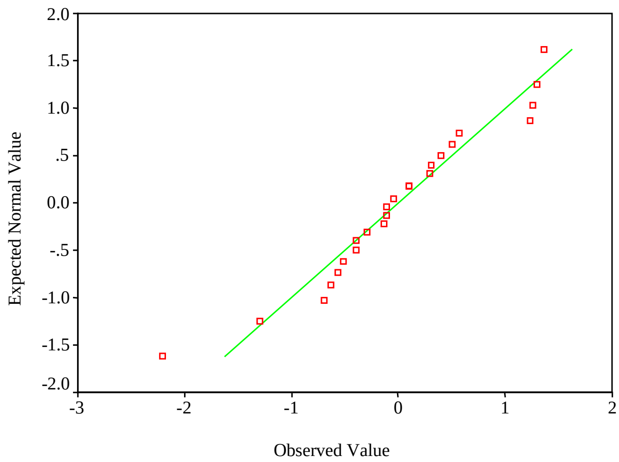

Figure 4.14. Normal Q-Q plot of standardised residual for Lmax.

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
	Observe	Expected	Observe	Expected	
	d		d		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.