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Mean dive times ranged from 34.5 to 52.1 minutes. These are similar to values reported for Azorean sperm whales by Gordon and Steiner (1992). The mean surface time for encounters in this study was 9.7 minutes which is in good agreement with the mean surface interval of 9.4 minutes reported by MacGibbon (1991).

Surface time was significantly correlated with dive time (Pearson's p-m Correlation Coefficient, p=.000). As would be expected longer dives required longer periods of recovery.

Fluke to fluke time was also significantly correlated with the minimum depth recorded in each 5 km square (Pearson's p-m Correlation Coefficient, p=0.026). Fluke to fluke time increased with minimum depth, i.e., whales made shorter dives in shallower water. This agrees with the theoretical prediction (Gordon, 1987) that longer dives would become more profitable as travel times to feeding depth increased.

3.2.5 Headings and movements.

The distribution of fluke headings observed during the study is shown in Figure 12. Headings were not evenly distributed between sectors (Chi Squared Test, p=0.001). In particular few whales were seen heading south west or north east.

The bearing between subsequent fluke-up positions was found to be independent of fluke heading. This indicates that fluke heading was not a good predictor of actual direction of movement.

Example plots of the movements of two individual whales are shown in Figure 13. They illustrate a tendency for whales to stay in much the same area, which was particularly marked in the case of "White Dot".

Travel rates between fluke positions ranged from 0.2 to 2.2 knots (mean 1.1 knot). These were substantially slower than the travel speed of 2-3 knots reported by Mullins *et al*. (1988) for whales off Nova Scotia but similar to speeds of between 0.86 and 1.6 knots for two whales off Madeira (Ohlsohn1991).

3.2.5.1 CHANGES IN HEADING DURING ENCOUNTERS. Changes in heading were observed during 50% of encounters. Where changes were observed the average change recorded was 45° and the maximum a complete turn of 180°. The difference between initial and final headings was positively correlated with surface time (Pearson's p-m Correlation Coefficient, p=0.000). No significant effects of the presence of tour boats, the total number of boats within 450 m or the range of the whale from the study vessel on the magnitude of changes in heading were detected.

3.2.6 Blow rates.

Mean blow intervals for encounters with unidentified whales and different identified individual whales are presented in Table 2. The overall mean blow interval for whales in this study was 17.20 seconds. This is a little higher than the mean rates reported by MacGibbon which were 16.31 seconds when no boats were present and 15.07 seconds when boats were present.

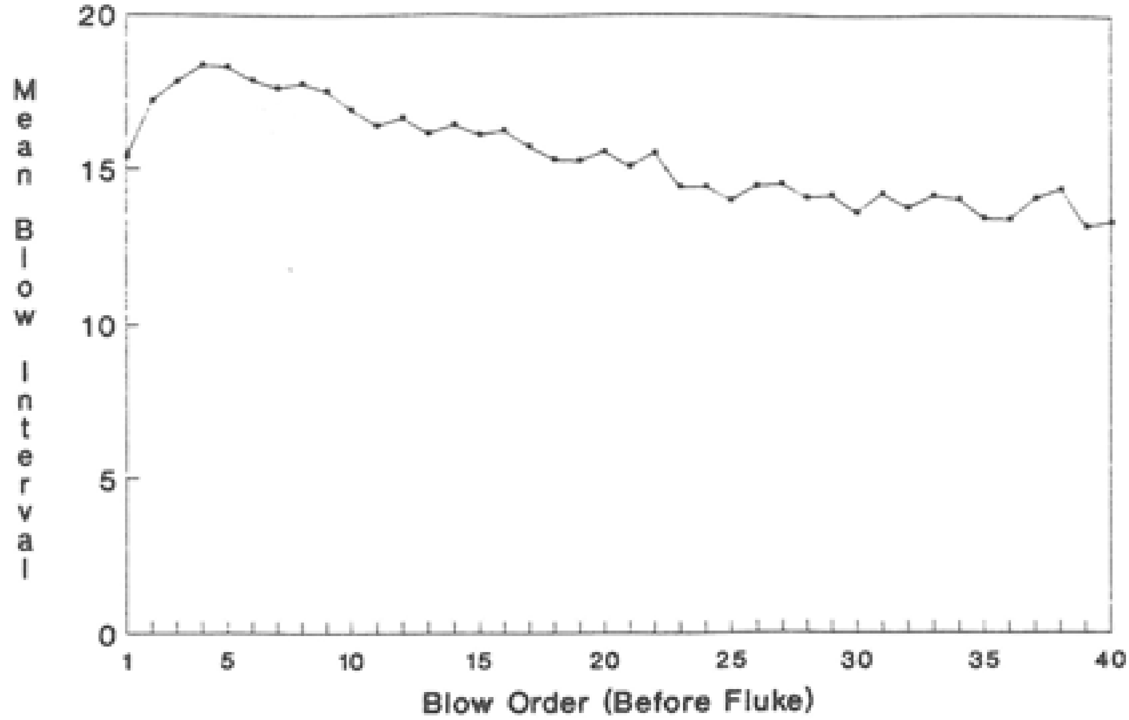

Figure 14 Mean values of blow intervals (seconds) through surfacing. Blow order is with reference to fluke up. First interval before fluke up is one, interval before that is 2 etc. Time travels from right to left. Mean blow interval 1 is mean for all encounters of all first blow intervals before fluke up, etc.

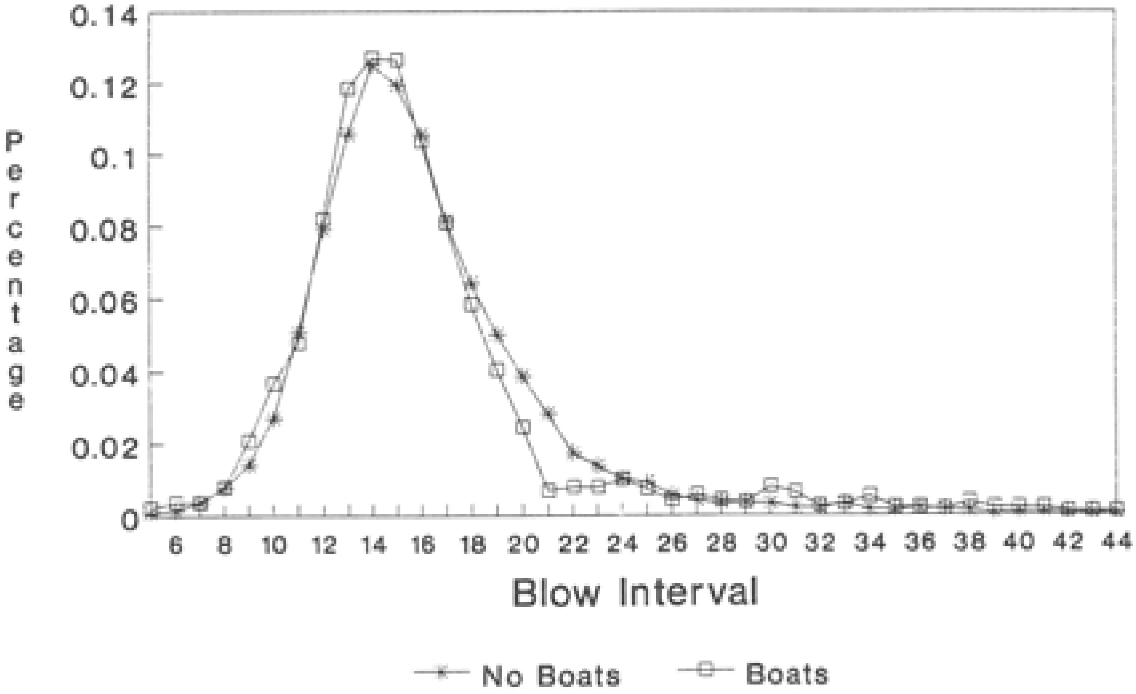

Figure 15 Distributions of all blow intervals (seconds) logged from encounters with and without whale-watching boats present .

Mean blow intervals in this study are larger than those measured by Gordon and Steiner (1992) from females and young males (12.0 seconds), and a little smaller than the values observed for mature males (18.2 seconds).

The standard deviation of blow intervals within an encounter was found to correlate positively with mean interval. This effect was removed by dividing standard deviation by the mean for each encounter and this parameter "SD/mean" has been used in statistical tests as a measure of the variability of blow intervals within encounters.

Blow intervals varied through a surfacing, becoming longer as the surfacing progressed but shortening just before the whale fluked (Figure 14). This is similar to the pattern observed for undisturbed sperm whales off the Azores (Gordon and Steiner, 1992). These authors proposed that the decreasing blow rate through a surfacings may reflect a diminishing "urge to breath" as carbon dioxide is removed from the body and oxygen reserves replenished. The increase in rate just before fluking could be a hyper-ventilation to reduce carbon dioxide levels before diving.

3.3 Investigations of Sources of Variation in Surface Behaviour

The results of analyses of surface behaviour conducted according to the schedule outlined in Figure 5 are summarised in Table 3.

3.3.1 Dives without Fluking

Approximately 10% of encounters ended when whales submerged without fluking up. This behaviour is often exhibited when whales have been disturbed (Gordon pers. obs.; MacGibbon, 1991). MacGibbon (1991) reported that 84% of submergences when boats were present occurred without fluking whereas only 6% of submergences were not preceded by flukes when boats were absent. (Direct comparisons between the two studies are not possible due to differences in the way the data were collected. It is not clear whether some of MacGibbon'sshorter submergences would have been scored as the end of encounters in this study.)

The frequency of encounters ending without fluking was not significantly higher when tour boats were present (Chi-square test, $p>0.05$). However non-fluking encounters when no tour boats were present had long surface times and high blow intervals, indicative of resting whales, while non-fluke dives in the presence of boats had short dive times and low mean blow intervals, suggesting that these were whales which had been disturbed. Resting whales which are less vocal and less conspicuous on the surface would be less likely to be found by whale watching boats.

This is a somewhat confusing result which seems to reflect the interaction of two different factors. If it is accepted that the whales which fluked up in the absence of tour boats were resting whales which would rarely be found by whale watching operators then it would appear that on 10% of occasions whale watching vessels caused whales to dive hurriedly without raising their flukes. Whales which are made to dive hurriedly will have had less time to replenish oxygen stores and the subsequent dive might be expected to be shorter than it would otherwise have been. The potential effect of this on feeding is discussed in Section 4.3.

The analyses of surface parameters in the rest of this report were conducted using only data from encounters where whales did fluke up. These analyses are therefore investigations of effects in addition to the hurried, non-fluke dives discussed in this section.

3.3.2 Differences in surface behaviour between individual whales.

MacGibbon (1991) showed that individual whales varied in their behaviour and in their responses to tour boat activities, thus the tests in Series 2 (Table 3) were designed to investigate the differences in behaviour between different individual whales. In most cases surface behaviours such as mean blow rates, surface times, numbers of blows per surfacing and dive cycle parameters, were shown to vary significantly between different identified individuals, and between them and unidentified whales.

It is important to control for these effects in any analyses designed to investigate the effects of tour boats on behaviour. Whale-watching boats were more likely to encounter and work with some individuals than others. Also, MacGibbon (1991) has shown that some whales were shy of boats while others were habituated.

"White Dot", appeared to be exceptional amongst the whales and often exhibited unusual behaviour. For example, he occasionally surfaced tail-first while emitting rapid trains of clicks. Todd (1991) has described exuberant behaviour, including tail first surfacings, from other well known whales, "Hoon" and "Groove". Like "White Dot", "Hoon" was a whale with a predictable geographical location which was tolerant of the approach and activities of whale watching boats and which received a lot of attention from them (MacGibbon, 1991). "Hoon" was not seen during our study. **A** dead sperm whale seen at sea in late 1991 was believed to have been this individual (Oliver pers. comm.).

3.3.3 Variation due to location.

Behaviours of unidentified whales with no tour boats present were compared between encounters in the two zones (shelf and offshore; Figure 2) using Mann-Whitney U tests. Identified whales were excluded from the analysis because these individuals were only found in the shelf region. Mean blow intervals for encounters in the offshore zone were higher than those for encounters in the shelf zone but this was not significant at the 5% level. There were insufficient data to compare fluke to fluke and estimated dive times between zones. Other variables did not show significant differences.

3.3.4 Variation due to the presence of whale watching boats.

3.3.4.1 GENERAL OBSERVATIONS**.** Whales were occasionally seen to be clearly disturbed by the activities of whale watching vessels. Typical behaviours observed from such whales were the showing of side-flukes and head-outs above the surface, sudden changes of direction and diving without raising flukes above the surface.

These occurrences could almost always be attributed to insensitive driving by a whale-watch boat skipper, i.e., failure to follow the guidelines and recommendations in MacGibbon 1991.

3.3.4.2 ANALYSIS OF SUMMARY STATISTICS. A comparison of measures of surface behaviour using the complete data set (Mann Whitney U tests, Series 1) showed significant differences in surface times and numbers of blows between encounters when tour boats were absent or within 450 m. Fluke to fluke times and dive times (for the dives following the encounter) were not significantly different. Table 4 shows values of these parameters for the full data set in the presence and absence of boats. These trends were in the same directions as those shown by MacGibbon (1991).

Figure 15 shows the distributions of all blow intervals logged in the presence and absence of tour boats. Although the two distributions look very similar a Kolmogorov-Smirnov 2-sample tests showed that the two distributions were significantly different (p=0.036).

Data for encounters from the shelf edge zone and from the offshore zone were analyzed separately. In the offshore zone, significant differences were observed in the mean blow interval due to the presence of tour boats (Mann Whitney U test, p=.001). In the shelf zone, significant differences were observed in the number of blows and surface time (Mann-Whitney U test, p=.003, p=.031) also due to the presence of boats.

For unidentified whales (Series 3), there were significant differences in mean blow intervals and surface times between encounters with and without tour boats present. No significant differences were observed for the same parameters for the identified individual “Wh 13” (Series 5).

When "White Dot's" data were analyzed (Series 4) the only parameter showing significant differences between encounters when boats were and were not present was estimated dive time which was higher when boats were present. "White Dot" was a "resident" whale which was well known to the whale watching skippers and received a lot of boat attention. The boat skippers reported "White Dot" to be easy to work with and our own observations in the field suggested that this was a tolerant whale. This may explain why analysis of this data set did not show the same significant differences in behaviour as the unidentified whales. (It must also be noted that the data sets for "White Dot" were much smaller than for the unidentified whales and this would also lead to reduced levels of significance).

3.3.4.3 EFFECTS OF TOUR BOATS ON PATTERNS OF BLOW INTERVALS THROUGHOUT A SIGHTING. Figure 16 shows a plot of the mean standardised blow interval for sequential blows through a surfacing, for data from boat and non-boat encounters. Blow order is considered relative to the time of fluke-up. Thus "1" is the mean of all the standardised intervals immediately before fluke up for all encounters recorded in this study. Note that time runs from right to left and that points further to the right are based on a decreasing amount of data. The two distributions are very similar and in particular both show the same decrease in blow interval prior to fluking up. A Kolmogorov-Smirnov 2-sample test indicated no significant differences between the two distributions (p=0.531). If whales were being forced to fluke hurriedly this feature might be expected to be missing. In her study MacGibbon (1991) observed that when boats were present many dives were not preceded by the normal pre-dive sequence.

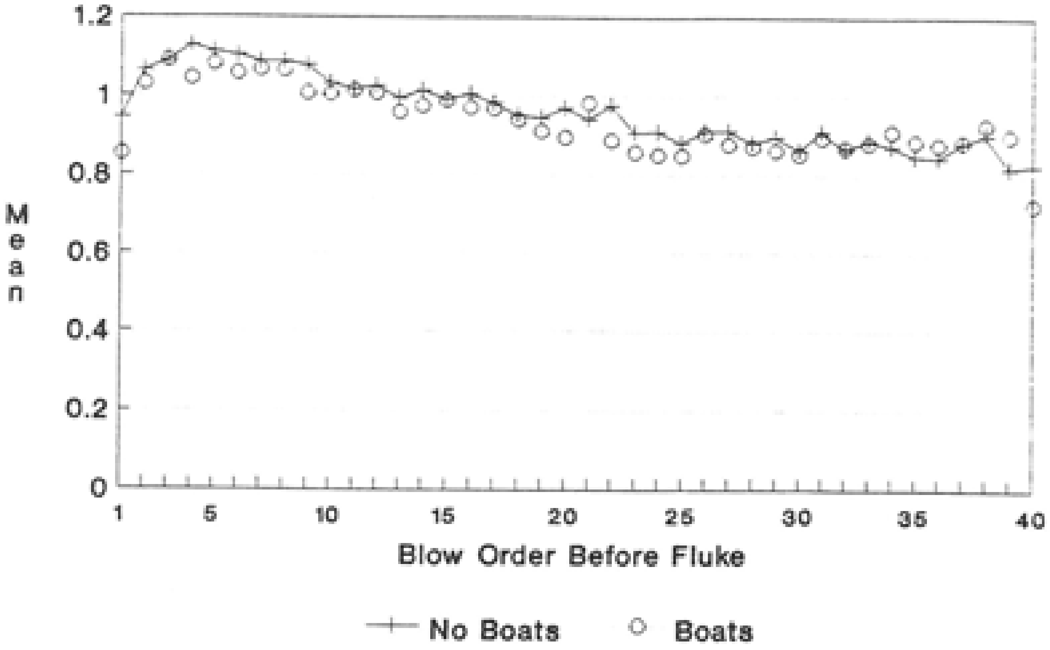

Figure 16 **Mean values of standardised blow intervals against blow order for encounters with and without boats present. Standardised intervals are blow intervals divided by the mean blow for that encounter.**

3.3.4.4 EFFECTS DUE TO NUMBER OF BOATS. No significant changes in blow rates, surface times or numbers of blows were found for encounters with different numbers of whale watching boats (from one to four) within 450 m, when compared using Kruskal-Wallis tests 0.797, p=0.661).

Similarly there were no significant effects due to the number of boats at or within 50 metres when only data from the encounters for which there was at least one boat at or within 50 m were considered (Kruskal-Wallis, p=0.854, p=0.058, p=0.151). This is in contrast to MacGibbon (1991) who found that effects due to boats increased as more boats were present.

3.3.4.5 POSITIONS OF BOATS RELATIVE TO WHALE. Boats at or within 50 m of the whale were initially assigned to six 60° sectors. Boats were scored in the front two sectors about one third as often as in the other sectors and were scored in all other sectors at much the same rate.

These sectors were grouped into two larger sectors. The front 60^o on either side were combined as the "front sector". Mean blow rate, surface time and number of blows were compared for encounters with boats present in the "front sector" with those with boats scored at or within 50 m but with none being scored in the front sector (Mann-Whitney U tests; p=0.929, p=0721, p=0.843).The two rear 60^o sectors were combined as the "rear sector" and parameters were compared in the same way. No significant effects due to positions of boats were found for the same parameters (p=0.883, p=0.688, p=0.638).

MacGibbon (1991) reported that whales were particularly likely to be frightened if boats went ahead of whales or approached them from directly behind. Field experience working with sperm whales over many years in the Azores and Sri Lanka has shown that sperm whales are readily approachable from the rear but are frightened when approached from the side and especially the front. However these observations are not supported by this analysis.

3.3.4.6 COMPARISON OF SURFACE FOR THE SAME WHALES BEFORE AND AFTER ENCOUNTERS WITH TOUR BOATS. On 21 occasions data was collected from the same identified individual which allowed comparison of behaviour when boats were present with behaviour during the previous or subsequent encounters. Thirteen of these encounters were with "White Dot". Table 5 shows the results of Wilcoxson matched-pairs signed rank tests of surface parameters. Surface times were significantly shorter and blow numbers significantly lower for encounters with tour boats compared to subsequent encounters with no tour boats present. The standard deviations of blow intervals for each encounter were higher when boats were present than for both the previous and subsequent encounters, indicating that whales blew more erratically when boats were present.

The data for "White Dot" showed the same significant differences for surface times and blow numbers but not for standard deviation of blow intervals.

3.3.5 Aeroplanes and helicopters.

No obvious changes in behaviour were observed which could be directly attributed to the presence of aircraft. One pilot reported that whales were only startled if the shadow of the aircraft happened to pass over them and pilots were usually able to prevent this happening.

Surface behaviours were compared in the presence and absence of aircraft (aeroplanes or helicopters), for encounters with tour boats present and encounters without tour boats using Mann-Whitney U tests. For boat encounters mean blow interval and surface times were longer, and number of blows were higher, when aircraft were present (Mann-Whitney U test, p=0.002, p=.041, p=.006). Blow interval, surface time and number of blows were also higher for no boat encounters when aircraft were present but only number of blows was significant at the 5% level (p=0.807, p=0.055, p=0.28).

Table 5. Summary of p values for Wilcoxson matched-pairs signed-rank tests of values of surface behaviour for encounters before during and after tour boat encounters.

“WHITE DOT” AND OTHER IDENTIFIED WHALES

	Boat encounter v previous encounter n=14	Boat encounter v subsequent encounter n=16	Previous encounter v subsequent encounter n=9
Mean	0.623	0.409	0.953
Standard dev’n	0.048*	0.017*	0.859
Blow number	0.706	0.007*	0.761
Surface time	0.683	0.006*	0.767
Fluke to fluke time	0.959 (n=10)	0.314 (n=9)	0.889 (n=8)
Dive time	0.646 (n=10)	0953 (n=9)	0.779 (n=8)

“WHITE DOT” ONLY

	Boat Encounter v Previous Encounter n=9	Boat Encounter v Subsequent Encounter n=11	Previous Encounter v Subsequent Encounter n=7
Mean	0.678	0.286	1.000
Standard dev’n	0.213	0.075	0.866
Blow Number —	0.236	0.005 **	0.866
Surface Time	0.260	0.005 **	1.000
Fluke to Fluke Time	0.866 (n=7)	0.600 (n=6)	0.600 (n=6)
Dive Time	0.500 (n=7)	0.753 (n=6)	0.463 (n=6)

“n” indicates number of paired comparisons made.
Numbers in brackets indicate sample size when smaller than shown at head of columns.

These effects are in the opposite direction to the significant effects due to boat presence, which showed reduced mean interval, blow number and surface times. An explanation for this result may lie in the way in which both the study boat and the whale watching vessels made use of information from aircraft to find whales. Aircraft pilots shared information on the location and behaviour of whales with the skippers of the whale-watching vessels, on a casual basis, using radio. Both the whale watching vessels and the study vessel would use a circling aircraft as an indication that a whale was on the surface below the aircraft.

The increase in surface time and number of blows scored when no boats were present, is probably an effect of the research crew seeing an aircraft divert to, or circle over, a whale on the surface and consequently being able to spot it earlier than they would otherwise have done. The same factors may explain some of the effect on surface time and number of blows when boats are present. In addition aircraft were probably more likely to lead the study boat and tour boats to resting whales. Because these whales were often not vocal and blew less strongly they would be less likely to be found by whale watching boats operating alone. Resting whales spent longer on the surface and had a longer blow interval than feeding whales.

3.4 Vocal Behaviour

3.4.1 General observations.

Vocalisations were rarely heard from whales on the surface. **Regular clicking** started soon after the whale fluked up. On 11 occasions (7% of total) **trumpet** vocalisations were heard after whales fluked. The mean interval between fluking up and the start of regular clicking was 31.9 seconds when no trumpets were heard and 74.6 seconds when trumpets were heard. Whales were vocal for most of the time that they were underwater making sequences of regular clicks at rates of around 1-2 s^{-1}, interspersed with creak vocalisations and silences. Whales stopped regular clicking before they reached the surface. The mean interval between the cessation of clicking and whales being seen at the surface was 5 minutes 30 seconds.

The overall mean **creak rate** observed in this study (12.1 creaks hr^{-1}) was higher than that observed by Mullins *et al.* (1988) (1.1 creaks hr^{-1}) and Ohlsohn (1991) (approximately 9 creaks hr^{-1}). If creaks are associated with feeding this would indicate that Kaikoura is a favourable feeding area as other workers have suggested.

Spectral analysis of individual clicks within creaks showed dominant frequencies to be between 3.5 and 4.5 kHz. If creaks are indeed echolocation runs, and these emphasised frequencies are the ones of most importance, then background noise at these frequencies will be most effective in masking echo returns and the most disruptive of echolocating ability. Table 2, Appendix 1, shows that the peak frequencies for the vessels used for whale watching off Kaikoura travelling at cruising speed or top speed are between 3 and 4 kHz.

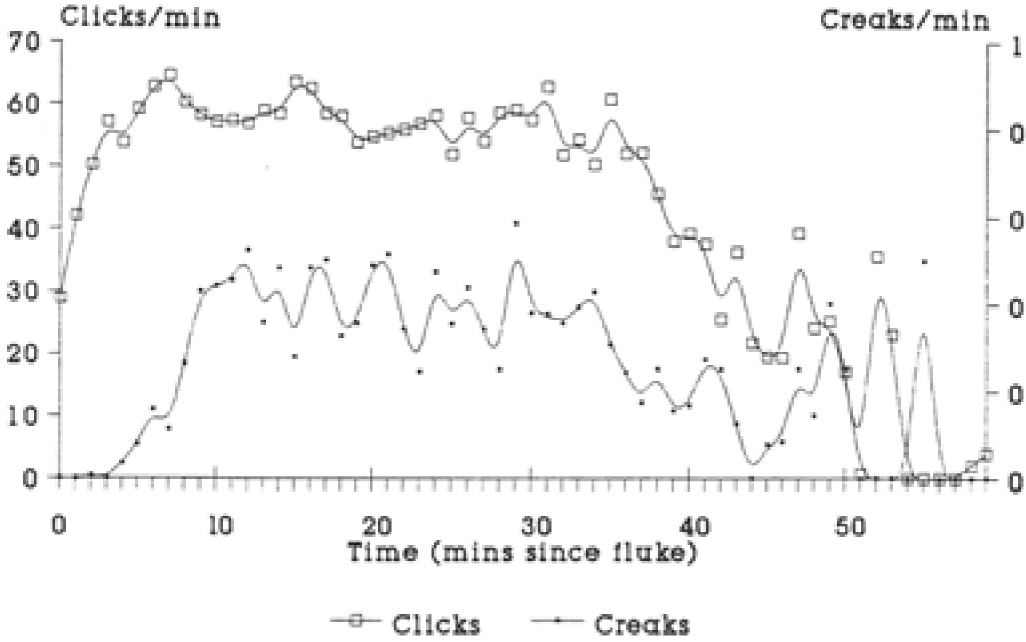

Figure 17 **Mean (over all analysed encounters) click rates and creak rates for each minute after fluke up.**

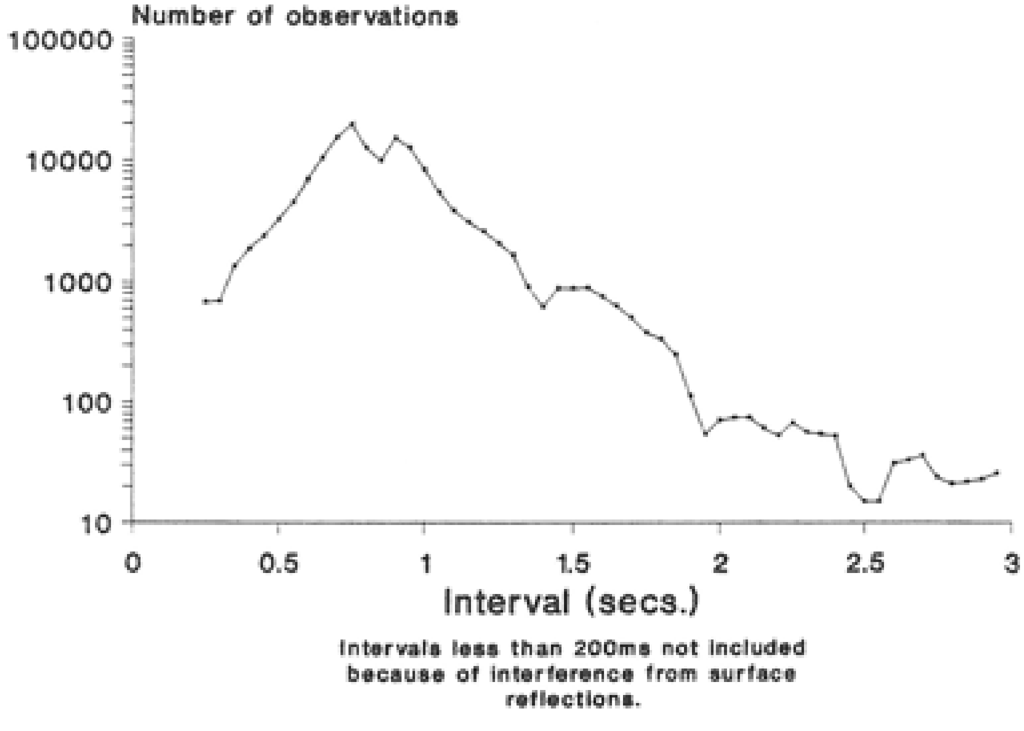

Figure 18 **Frequency distribution of all inter-click intervals measured.**

Clangs (resonant sounding clicks with a long interclick interval) were frequently heard although they were only ever positively attributed to one animal ("White Dot") which produced clangs during most surfacings. Clangs were usually heard either just before a whale came to the surface, when it was at the surface, or just after a fluke up. They were typically produced in sequences of three to seven clangs with inter-clang intervals ranging from four to eight seconds.

Todd (1991) reported hearing clangs from other "resident" whales, "Hoon" and "Groove" as well as "White Dot". These were all whales which received a lot of attention from whale watching vessels. Although these whales appeared to be very tolerant of whale watching vessels this observation raises the possibility that clangs were in some way related to high levels of exposure to tour boat activity. Clangs could be used for echolocation, perhaps to discover the location of boats at the surface. In other areas "Clangs" have often been heard when mature males join mixed groups of females and young (Section 1.6).

The only other vocalisations heard from whales on the surface were rapid clicks and codas. **Rapid clicks** are believed to be echolocation vocalisations used to investigate objects on the surface. **Codas** are usually heard in social contexts (Section 1.6). They were only heard on two days during this study.

Figure 17 shows mean numbers of clicks and creaks per minute, for each minute following fluke up, for all encounters. Click and creak activity rose sharply during the first 10 minutes of the dive and was highest throughout the middle part of the dive. A steady decline in click activity occurred from about 35 minutes after to 46 minutes after fluking, which corresponded to the mean dive duration. The increase in irregularities with time in Figure 17, especially after 45 minutes, reflects the decreasing number of data points contributing to these later mean values (Figure 3).

3.4.2 Interclick intervals.

Figure 18 shows the number of observations of each interclick interval for data combined from all encounters. Table 6 shows the mean of the modal interclick interval for all dives scored for each of the five animals most frequently encountered. Modal interclick intervals showed significant differences between individual animals (Table 6).

Modal interclick interval was found to correlate positively with the minimum depth in the 5 km grid square containing the fluke position (Pearson p-m correlation, $p=0.009$). If regular clicks are used for long range echolocation, then inter-click interval would be expected to increase with water depth if the echolocating whale waited for all echoes and reverberations to return from the most distant large reflecting object (either the bottom or the surface) before making the next click. Many animal and man-made sonars work in this way.

Plots of successive interclick intervals against time (e.g., Figure 19) show that interclick intervals tended to vary in a regular manner. Sudden sustained changes in interclick interval (see Figure 20 for examples) were observed at some time during 24% of encounters. These sudden changes were most marked during the first few minutes of the dive and often involved click rates changing by close to a factor of two.

Examination of plots of click interval against time enabled encounters to be divided into two categories according to whether or not sudden changes were observed. Mann Whitney U tests between these two data sets for both visual and acoustic parameters gave the following significant differences:

Surface Time	($p=0.018$)
Mean blow interval	($p=0.012$)
Time to first creak	($p=0.012$)
Interclick at end of first bout	($p=0.000$)
Change in interval during first bout	($p=0.000$)
Length of first silence	($p=0.003$)

Table 6. Summary of some Parameters of Acoustic Behaviour

	No. of encounters	Time to first click s	Click rate s^{-1}	Modal click interval s $x10^{-2}$	Creak rate $x10^{-3}$ s^{-1}	Creak activity $x10^{-3}$ s^{-1}
Unident whales	63	56.1 55.9	0.79 0.21	80.8 23.4	5.98 8.19	1.97 2.69
White Dot	55	21.2 5.2	0.89 0.15	84.4 20.2	8.28 13.4	3.51 3.44
Wh 13	14	17.9 14.9	0.94 0.15	62.5 14.6	10.9 7.21	4.33 3.29
Groove	6	13.3 2.3	1.04 0.09	75.0 0.0	5.94 4.12	4.25 2.55
Wh 9	6	35.2 24.1	0.76 0.31	86.7 40.5	4.13 5.54	1.73 1.54
Wh 8	5	20.4 9.4	0.76 0.10	91.0 16.0	4.02 8.90	0.41 0.90

Upper figure is mean value
Lower figure is standard deviation

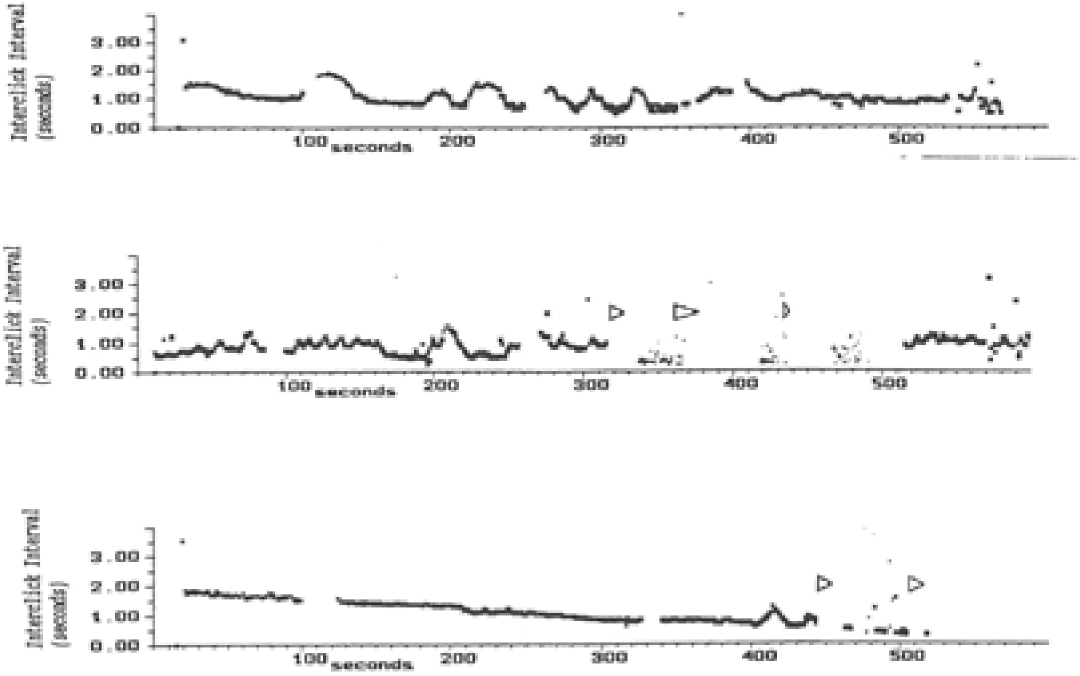

Figure 19 Examples showing plots of click intervals (s) against time in seconds since fluke up. Note that blow intervals tend to vary regularly. Horizontal triangles indicate creaks, and the length of triangle indicates duration of the creak

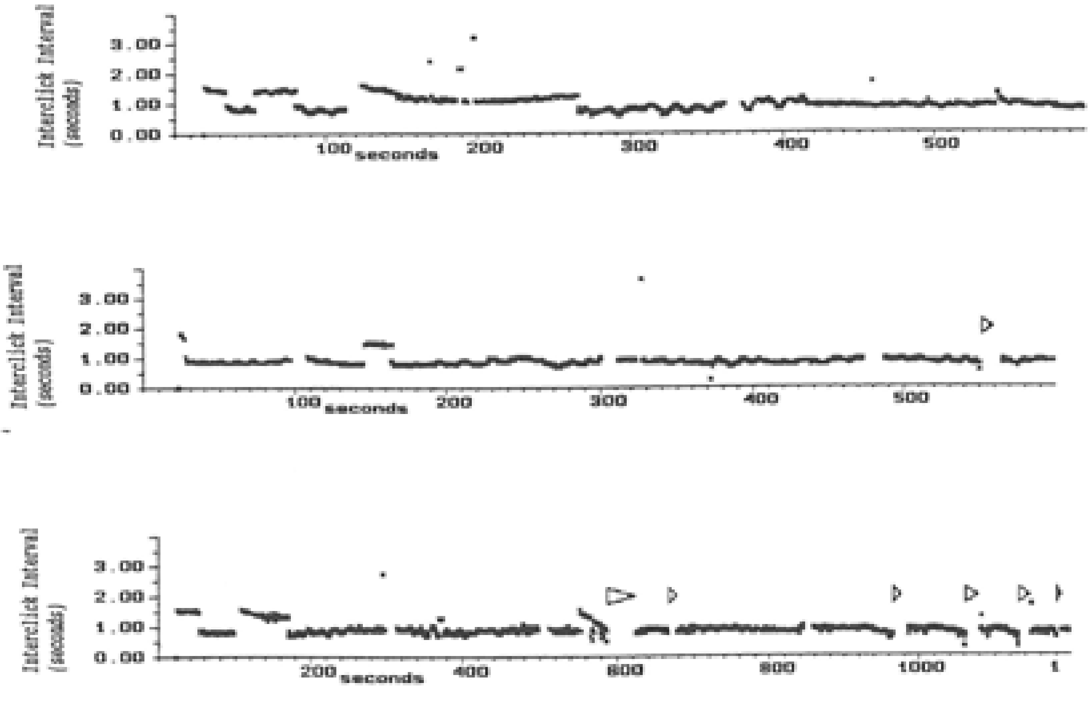

Figure 20 Example plots of inter-click intervals (s) against time since fluke-up showing the occurrence of sudden changes in click interval. Horizontal triangles indicate creaks, and the length of the triangle indicates duration of the creak.

The significant differences between interclick interval at the end of the first bout and change in interval during the first bout could be anticipated because any sudden change in interval will have a direct effect on these values. During encounters where sudden changes in interclick interval occurred, the mean length of the first silence was 12 seconds compared to 22 seconds for encounters with no sudden changes. Encounters where sudden changes were observed had shorter surface times, faster blow rates and a longer time period before the first creak. The number of encounters where sudden changes were observed was significantly higher in the "shelfzone"(25% of encounters) than the "offshore zone" (4% of encounters) (Chi-squared test, p=0.894). The frequency of encounters with sudden changes or with trumpet vocalisation were not related to the presence of tour boats (Chi-square test; p=0.894, p=0.560).

Sudden sustained changes in click rates have not been previously described for sperm whales. It is hypothesised that they may occur when whales are echolocating using regular clicks and are only interested in targets at less than half the range to the largest reflective object. In this situation they can double their click rate and still avoid interference between reverberation and target echoes.

3.4.3 Sources of variation in acoustic parameters.

The results of the series of statistical tests of acoustic parameters conducted according to the schedule outlined in Figure 5 are summarised in Table 7.

3.4.3.1 VARIATION BETWEEN INDIVIDUALS. The series of tests (Series 2) designed to show between individuals revealed significant results for many parameters. Time to first click, mean clicks per second, modal clicks per second and creak activity were particularly likely to show significant differences between individuals.

3.4.3.2 VARIATION DUE TO LOCATION. Comparison of data from the "shelf zone" with that from the "offshore zone" for unidentified whales with no tour boats present (Series 6) showed significantly different values for mean click rate, creak activity, length of first silence and mean interclick interval at the end of first bout. The higher click rate probably reflects the shallower water in the shelf zone and the relationship between modal inter-click interval and water depth discussed in Section 3.4.2. The higher creak activity may indicate a higher rate of feeding in the shelf zone.

3.4.3.3 VARIATION DUE TO WHALE WATCHING BOATS. None of the series of tests investigating the effects of whale watching vessels on vocal behaviour (Series 1,3,4,5) were significant at the 5% level. In addition no obvious changes in acoustic behaviour or distinctive vocalisations were detected in response to the presence of boats or to high levels of boat noise.

Table 7. Results of statistical tests on acoustic parameters

Series 1

DATA SELECTED FOR ANALYSIS: All data. (n=165)
INDEPENDENT VARIABLE: Presence or absence of tour boats within 450m.
TEST: Mann Whitney U test.

First clicks	.356	Time to 1st Crk (104)	.299
Length 1st Clk (159)	.176	Creak rate (104)	.475
Duration first silence	.372	Creak activity	.425
Mean initial Int. (159)	.452	Mean Clk interval (104)	.184
Mean final Int. (157)	.301	Modal Clk interval	.513
Change in Interval (157)	1.000	Percent modal Int.	.674

Series 2

DATA SELECTED FOR ANALYSIS: No boats present (n=111)
INDEPENDENT VARIABLE: Identity of whale
TEST: Kruskall-Wallis test

First clicks	.007**	Time to 1st Crk (104)	.785
Length 1st Clk (159)	.121	Creak rate (104)	.016*
Duration first silence	.0.25*	Creak activity	.007**
Mean initial Int. (159)	.005**	Mean Clk interval (104)	.040*
Mean final Int. (157)	.000***	Modal Clk interval	.011*
Change in Interval (157)	.456	Percent modal Int.	.001***

Series 2.1

DATA SELECTED FOR ANALYSIS: Encounters with unidentified whales and White Dot with no boats present (n=86).
INDEPENDENT VARIABLE: Identity of whale
TEST: Mann Whitney U test.

First clicks	.036*	Time to 1st Crk (104)	.727
Length 1st Clk (159)	.634	Creak rate (104)	.002**
Duration first silence	.004**	Creak activity	.010**
Mean initial Int. (159)	.001***	Mean Clk interval (104)	.014*
Mean final Int. (157)	.000***	Modal Clk interval	.165
Change in Interval (157)	.163	Percent modal Int.	.046*

Series 2.2

DATA SELECTED FOR ANALYSIS: Encounters with all identified whales excluding White Dot and with no boats present (n=25)
INDEPENDENT VARIABLE: Identity of whale
TEST: Kruskall-Wallis test

First clicks	.036*	Time to 1st Crk (104)	.700
Length 1st Clk (159)	.028*	Creak rate (104)	.052
Duration first silence	.100	Creak activity	.042*
Mean initial Int. (159)	.063	Mean Clk interval (104)	.042*
Mean final Int. (157)	.003**	Modal Clk interval	.003**
Change in Interval (157)	.495	Percent modal Int.	.001***

Series 2.3

DATA SELECTED FOR ANALYSIS: Encounters with all identified whales excluding White Dot and with no boats present (n=25)
INDEPENDENT VARIABLE: Identity of whale
TEST: Kruskall-Wallis test

First clicks	.302	Time to 1st Crk (104)	.328
Length 1st Clk (159)	.081	Creak rate (104)	.266
Duration first silence	.145	Creak activity	.050*
Mean initial Int. (159)	.056	Mean Clk interval (104)	.317
Mean final Int. (157)	.028	Modal Clk interval	.027*
Change in Interval (157)	.276	Percent modal Int.	.016*

Series 2.4

DATA SELECTED FOR ANALYSIS: Data from Shelf Zone with no boats present (n=82)
INDEPENDENT VARIABLE: Identity of whale
TEST: Kruskall Wallis test

First clicks	.034*	Time to 1st Crk (104)	.803
Length 1st Clk (159)	.099	Creak rate (104)	.025*
Duration first silence	.349	Creak activity	.141
Mean initial Int. (159)	.067	Mean Clk interval (104)	.058
Mean final Int. (157)	.018*	Modal Clk interval	.030*
Change in Interval (157)	.640	Percent modal Int.	.001***

Series 3

DATA SELECTED FOR ANALYSIS: Unidentified whales (n=73)
INDEPENDENT VARIABLE: Presence or absence of boats within 450m.
TEST: Mann Whitney U test.

First clicks	.975	Time to 1st Crk (104)	.090
Length 1st Clk (159)	.572	Creak rate (104)	.374
Duration first silence	.110	Creak activity	.941
Mean initial Int. (159)	.460	Mean Clk interval (104)	.492
Mean final Int. (157)	.205	Modal Clk interval	.663
Change in Interval (157)	.396	Percent modal Int.	.738

Series 4

DATA SELECTED FOR ANALYSIS: Encounters with White Dot (n=55)
INDEPENDENT VARIABLE: Presence or absence of boats within 450m.
TEST: Mann Whitney U test.

First clicks	.305	Time to 1st Crk (104)	.558
Length 1st Clk (159)	.245	Creak rate (104)	.399
Duration first silence	.598	Creak activity	.966
Mean initial Int. (159)	.613	Mean Clk interval (104)	.851
Mean final Int. (157)	.594	Modal Clk interval	.695
Change in Interval (157)	.993	Percent modal Int.	.429

Series 5

DATA SELECTED FOR ANALYSIS: Encounters with Whale 13 (n=14)
INDEPENDENT VARIABLE: Presence or absence of boats within 450m.
TEST: Mann Whitney U test.

First clicks	.184	Time to 1st Crk (104)	.197
Length 1st Clk (159)	.392	Creak rate (104)	.830
Duration first silence	.100	Creak activity	.755
Mean initial Int. (159)	.697	Mean Clk interval (104)	.667
Mean final Int. (157)	.102	Modal Clk interval	1.000
Change in Interval (157)	.024	Percent modal Int.	.186

Series 6

DATA SELECTED FOR ANALYSIS: Encounters with unidentified whales with no tour boats within 450m (n=53)
INDEPENDENT VARIABLE: Encounter position in offshore or shelf zone.
TEST: Mann Whitney U test.

First clicks	.197	Time to 1st Crk (104)	.531
Length 1st Clk (159)	.970	Creak rate (104)	.905
Duration first silence	.001***	Creak activity	.064
Mean initial Int. (159)	.154	Mean Clk interval (104)	.788
Mean final Int. (157)	.040*	Modal Clk interval	.566
Change in Interval(157)	.310	Percent modal Int.	.663

Tests 1,3,4 and 5 were designed to investigate the effects of tour boat presence on whale behaviour. Test 2 was used to examine the differences between individual animals, while Test 6 was used to investigate the effects of geographical location on whale behaviour.

Only data from encounters which ended in fluke up have been analysed.
"n" indicates sample size. Numbers in brackets indicate sample size if different from that shown at head of each section.

Table 8 p values for Wilcoxson matched-pairs signed-rank tests of values of acoustic parameters from encounters before during and after tour boat encounters.

	Boat encounters v previous encounter n=14	Boat encounter v subsequent encounter n=16	Previous encounter v subsequent encounter n=9
Length of 1st bout of clicking	0.730	0.856	0.213
Duration of silence after 1st bout of clicking	0.030*	0.017*	0.675
Initial mean interclick interval	0.9721	0.177	0.972
Mean interclick interval at the end of 1st bout	0.039*	0.212	0.173
Change in interclick interval during 1st bout	0.041*	0.280	0.260
Time from fluke to 1st creak	0.646 (n=10)	0.133 (n=13)	0.499 (n=7)
Creak activity	0.374 (n=9)	0.552 (n=13)	0.600 (n=6)
Creak rate	0.972 (n=13)	1.000	0.886 (n=8)
Mean click rate	0.333 (n=10)	0.917 (n=13)	0.499 (n=7)
Modal click interval	0.767	0.570	0.866 (n=8)
Percentage of clicks in modal interval	0.470	0.570	0.856
Occurrence of sudden changes	0.142	0.463	0.361

For definitions of acoustic parameters see Section 2.8.1
"n" indicates number of paired comparisons made
Numbers in brackets indicate sample size when smaller than shown at head of columns.

3.5 Comparison of Acoustic Parameters for the Same Whales Before and After Encounters with Tour Boats.

Table 8 summarises Wilcoxson matched-pairs signed-rank tests of acoustic parameters from the 21 encounters with identified individuals where it was possible to compare values of acoustic parameters measured during boat encounters with those from subsequent and/or previous encounters. There were significant differences for some parameters summarising the first bout of clicking after fluke up. The duration of the first silence was greater during boat encounters than encounters either before or after. The mean interval between the last five clicks in a sequence was higher for boat encounters than for encounters immediately before boat encounters and there was also a smaller change in click rate during the first bout of clicking.

Click interval normally decreases during the first bout of clicking. The higher click interval at the end of the first bout and the smaller change in click interval are thus probably two manifestations of the same effect. This decrease in click interval may occur because the echolocating whale is waiting for all echoes to return from the most distant large reflective surface (which for a whale which has recently dived would be the bottom) before emitting the next click. **As** the whale dives and gets closer to the bottom its echoes return more quickly and click rate can increase. If this was the case then a lower change in click rate would indicate a slower descent rate. This in turn would lead to a greater travel time to feeding depth and consequently a shorter time available for feeding.

The finding of few significant effects of tour boat activity on acoustic behaviour suggests that disturbance was limited to the time at and close to the surface. However this can not be taken as proof that tour boats were not modifying the whale's underwater behaviour in ways which were not detected. This has been the first study in which sperm whale vocalisations have been used as an index of underwater behaviour and it could be that some important parameters were not analysed. However, it is believed that the acoustic measures chosen were likely to have had biological importance. The validity of using sperm whale vocal behaviour as an index of disturbance is supported by the major changes in sperm whale vocal behaviour in response to underwater noise reported by Watkins *et al* (1985), (Section 1.4) and by the considerable differences in vocal behaviour between individuals and locations demonstrated in this study.

4. CONCLUSIONS AND COMMENTS

4.1 Variation in Between Individuals and Between Locations

This study has emphasised how different all aspects of the behaviour of individual whales can be, even when environmental conditions seem to be constant. Some whales seem to be more tolerant of whale watching boats and these individuals are the ones to which most whale watching effort is directed. Such whales could be inherently more tolerant of boats or could have become habituated to them over time. Conversations with whale-watching skippers suggest that both of these processes could have played a part.

There were some differences in the behaviour of whales in the shelf and offshore zones. These may have been due to physical and biological differences between the two regions as well as to differences in the individual whales found in the two areas. Creak activity and click rates were higher in the shelf zone than in the offshore zone suggesting a higher rate of feeding on the shelf. Blow rates were lower offshore, which may indicate resting whales. Similar observations were made off Sri Lanka. Here, Gordon (1987) found that on the edge of the continental shelf (in waters between 500 and 1000 metres) there were more encounters which ended with the whales fluking up, fewer non-fluking submergences, and group size was smaller than in offshore waters (1000 m+). This was interpreted as an indication that feeding whales were more common in the shelf-edge area and resting and socialising whales more common offshore.

Whales which were resighted over several days were only found in the shelf zone and some, such as "White Dot", were found within a very specific range. This tendency towards longer term residence on the shelf edge zone may be related to differences in feeding conditions in the two areas. Contrasting feeding behaviour by different whales is suggested by the work of Gaskin and Cawthorne (1967) who found that individuals caught off New Zealand often had stomach contents which consisted either completely of squid or were dominated by fish.

Different food and feeding conditions might favour different foraging strategies. For example, it may be most profitable for whales feeding on the shelf edge to know, and to continuously use, a good feeding patch. "Whale 13" and "White Dot" (two of the most commonly sighted individuals in the shelf zone) had the highest creak rates which could be interpreted as indicating that they experienced the best feeding. In such situations it could pay an animal to maintain an exclusive territory.

We saw no aggressive interactions between whales but "White Dot" was observed to clang regularly and frequently near and at the surface. Weilgart and Whitehead (1988) have suggested that clangs may be made to display an individual's competitive ability. In offshore areas whales were never resighted on more than one day. Whales there may have been passing through or feeding over a much larger area.

The similarities in behaviour between "White Dot" and another "resident" whale “Hoon”, well known from previous work, are remarkable. Both occasionally surfaced tail first and both produced clangs at or near the surface (Todd, 1991, reported these behaviours for another “resident” whale, "Groove", as well). These tolerant resident whales received a lot of attention from whale watching boats. An obvious interpretation of these observations is that these unusual behaviours were the result of the attention of whale watching vessels. It isn't possible to refute this suggestion. However, they seemed to be less affected by boats than other whales

(MacGibbon,1991; this study) and these behaviours don't seem to be obviously detrimental, or to be adapted to alleviating boat disturbance.

In attempting an investigation of the effects due to the activities of whale watching boats it is important to control for the effects due to individuals and to location. This is particularly important because some individuals received more attention from tour boats than others and certain areas were more likely to be visited than others (if only because they were close to the preferred transects of the whale watching operators).

During the study this control was not achieved satisfactorily with the complete data set. It was not possible to identify whales during all encounters, probably even during some encounters with well known individuals.

The division between shelf zone and offshore zone was very crude and the physical and oceanographic factors which were most important in determining the differences in behaviour between the two zones are not known.

This emphasizes the desirability of being able to observe the same whale before, after and during encounters with whale watching vessels. However such data has proved difficult to collect. One reason for this was that it was difficult to track whales through dives so as to be able to observe the same whale on a sequence of surfacings. The main problem was that of distinguishing the vocalisations of the "target" whale from those of other whales in the area. As a whale dived and moved away from the surface the amplitude of its clicks diminished and eventually could no longer be distinguished from those of other whales in the area.

Individuals could be reliably followed when the distribution of whales was such that the clicks of the target whale could always be clearly distinguished. Better results might be obtained with improved acoustic equipment (such as directional hydrophones which could be monitored underway and which could be kept trained on the target whale). Conditions might be more suitable for this approach the winter when a smaller number of whales use the inshore gully to the south of Kaikoura.

Another problem was that even when whales were tracked, whale-watching boats might not be present for some of the surfacings. Future studies could possibly adopt an experimental approach if the activities of whale watching boats could be directed. An experiment could involve observing a surfacing of a whale without boats present as a control, then arranging for boats to observe the whale on the next surfacing. However it is most unlikely that the behaviour of the boats in such controlled conditions would be representative.

4.2 Effects of Boats on Sperm Whale

There were still occasions when whales were disturbed by tour boat operators in ways which were immediately obvious and could have been avoided. This was usually caused by particularly insensitive boat-handling and often resulted in the whale submerging without fluking. This study suggests that there has been a reduction in the number of whales which were so obviously disturbed when compared to the observations of MacGibbon (1991). This can be attributed to more careful boat handling which in turn has been facilitated by the use of directional hydrophones. It must be hoped that boat handling will continue to improve. This may be helped by further advances in hydrophone technique and increased cooperation between boats and aircraft, to allow vessels to be positioned closer to surfacing whales.

In addition to such obvious disturbance there were indications of some statistically significant effects on surface behaviour. Mainly a tendency for surface times to be curtailed and for blow rates to increase (unidentified whales only). The data set for "White Dot" was the only substantial one for which it was possible to properly control for the effects of inter-individual variation and here there were no significant effects of tour boat activity on surface behaviour though there was an effect on estimated dive time.

The increase in dive time following the presence of tour boats for "White Dot" was surprising. Changes in this parameter might be considered to be more likely to be indicative of biologically significant disturbance than changes in the other parameters such as blow rate. Sperm whales dive to feed and changes in their dive behaviour could affect their feeding efficiency. In this respect the result would have been more alarming if dive times had decreased when boats were present. It is surprising that the whale which seemed to be most tolerant of boats should be the only one to show this effect.

The strongest evidence for an effect due to tour boat activity comes from analysis of serial data for occasions when the same whale was observed on surfacings before and/or after encounters with whale watching boats present. Tests with these data were more powerful because two of the major sources of variation in behaviour, location and individual identity, were controlled for. These data only came from identified whales and confirmed the finding of shorter surface times and lower blow number shown in the general data set for unidentified whales. They also suggest that blow rates were more variable when boats were present and that there were significant differences in the nature of the first bout of clicking after fluke-up. These results were significant when only "White Dot's" data were considered showing that even this whale which appears to be most tolerant of whale watching boats is being affected by them.

4.3 Biological Significance of Changes in Behaviour Associated with Whale-watching Activities

No measures of the long-term biological effects of the changes in behaviour indicated by this study have been made. However, some comments on their possible nature can be made, based on what is known of sperm whale biology.

The decrease in surface time and reduction in blow number is the factor which is most likely to be of major biological significance. Feeding whales are at the surface to prepare for deep feeding-dives. This study has shown a correlation between surface time and the length of subsequent dives; a relationship which would also be expected on physiological grounds. Thus, a reduction in surface time might lead to a reduction in the length of subsequent dives. Sperm whales appear to feed at considerable depths, thus each dive will have a substantial travel component both to the feeding depth and from that depth to the surface at the end of the dive. For any given feeding depth these times are likely to be constant. One effect of this is that a given percentage change in dive length will result in a larger percentage change in feeding time (Gordon, 1987).

This can be illustrated with a simple hypothetical example. In this study mean dive time was about 45 minutes. Mean time until first creak was about 12 minutes. This will be taken as travel time to the feeding depth. This is also approximately the length of time that a whale would take to travel 1000 metres at the descent rates (1.4 ms^{-1}) observed for diving whales by Gordon (1987). Gordon (1987) proposes that a diving whale's swim speed while travelling to feeding depth should be equal to that while returning to the surface. Thus the travel time to the surface will also be taken to be 12 minutes. Hence the total travel time is 24 minutes and the time available for feeding is 21 minutes. In this study, surface times were reduced by 17% when boats were present. Making the simple assumption that dive times will also be reduced by 17% gives a dive time of 37 minutes. Travel time remains the same at 24 minutes so that time available for feeding is now 13 minutes, a percentage reduction of 36%. The situation becomes rapidly worse if dive time is further reduced. This example is much simplified and the model outlined can not be used to make quantitative predictions, however, the effect it demonstrates must inevitably exist. Having said this, it must be noted that the data in this study did not indicate that dive times were reduced after encounters with boats present. However, the data for dive times were much fewer than for surface times.

There was also a reduction in the change of mean interval during the first bout of clicking. Typically the rate of clicking increases during this first bout. This may occur because the echolocating whale is waiting for all echoes to return from the most distant large reflective surface (which for a whale which has recently dived would be the bottom) before emitting the next click. As the whale dives and gets closer to the bottom its echoes return more quickly and click rate can increase. If this was the case then a lower change in click rate, as observed for tour-boat encounters, would indicate a slower descent rate. This in turn would lead to a greater travel time to feeding depth and consequently a shorter time available for feeding.

An echolocating animal has the problem of discriminating the echoes from its target from general background noise and from the reflections of its own echolocation vocalisations from non-target objects. Anything which increases the level of background noise should reduce the efficiency with which it can perform an echolocation task. For a feeding sperm whale this would probably equate to a reduction in the rate of feeding.

The vessels which are used for whale watching in Kaikoura do produce high levels of noise at frequencies which are close to those of clicks which make up creaks, and this is a cause for some concern. However in this study no effects of boat presence on creak rates have been demonstrated.

Little is known of the way in which the sperm whale echolocation system functions. It may be directional and other systems may exist for combating the effects of noise. Sperm whales must certainly contend with other sources of noise, including that from other vessels and from other whales.

4.4 Concluding comments

It should be emphasised that during this study most of the whale watching was taking place with tolerant whales (even though we may not have been able to identify them as such on every encounter). The findings, particularly as regards boat disturbance, may well not hold, if less tolerant whales become the subjects of the industry. The study also took place during the summer months. MacGibbon (1991) generally found that whales were more approachable in the summer than in the winter months.

Thus, we have been able to observe some immediately obvious effects of boats on whales, but note that there has probably been a considerable reduction of the degree of disturbance of whales by tour boat operators in recent years.

There are some additional effects on surface behaviour. These seem to be quite minor but it would be premature to assume that they had no biological significance.

Effects on underwater acoustic behaviour were only demonstrated in the bout of clicking immediately after fluke up. This could be taken to indicate that what effects there were on whale behaviour, occurred at or near the surface, and had limited effects on underwater behaviour.

Continuing monitoring would be advisable in order to investigate any long-term effects of this disturbance.

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Vassili Papastavrou proofread an earlier draft of this report.

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APPENDIX 1.

NOISE TRIALS

Al. Materials and Methods

Boat noise trials were carried out south of the peninsula in water between 500 and 1000 metres deep. The study vessel lay hove-to and a buoy was streamed on 50 metres of line. A bucket was tied to the buoy to act as a drogue and keep the line taut. A calibrated hydrophone consisting of a Benthos AQ-1 element with a low noise pre-amplifier with 30 dB gain was positioned 1metre below the surface so that it was 50 metres away from the buoy. Each boat was asked to pass as close as possible to the buoy at three speeds: full speed, cruising speed and the "no wake" speed (the speed at which a whale should be approached). Where possible more than one pass was made at each speed. A pass was classified as good if the boat passed within 3 metres of the buoy. (The error in sound level caused by a 3 metre error in measurement at 50 metres is 0.5 dB.) The signals from the hydrophone were amplified by a custom built amplifier giving approximately 34 dB of gain (this was calculated exactly for different frequencies) with a low pass filter of 21 kHz and high pass of filter of 1Hz. The amplified signal was then recorded on digital audio tape which was indexed at the time when the stern of the boat passed the buoy. **A** sample of 0.5 second duration, from close to the tape index, was analyzed using a Fourier transform based spectrum analysis package (Cambridge Electronic Design "Waterfal"software) running on a personal computer.

Some vessel signatures had peaks of similar amplitude which were widely spaced in frequency. The frequency of the peak with maximum amplitude sometimes varied between passes by the same boat at the same speed. The "peak frequency" for any vessel at any given speed was defined as the frequency at which the absolute maximum amplitude from all passes was observed. The mean of the amplitudes at this frequency was used to calculate a source level using the following equation:-

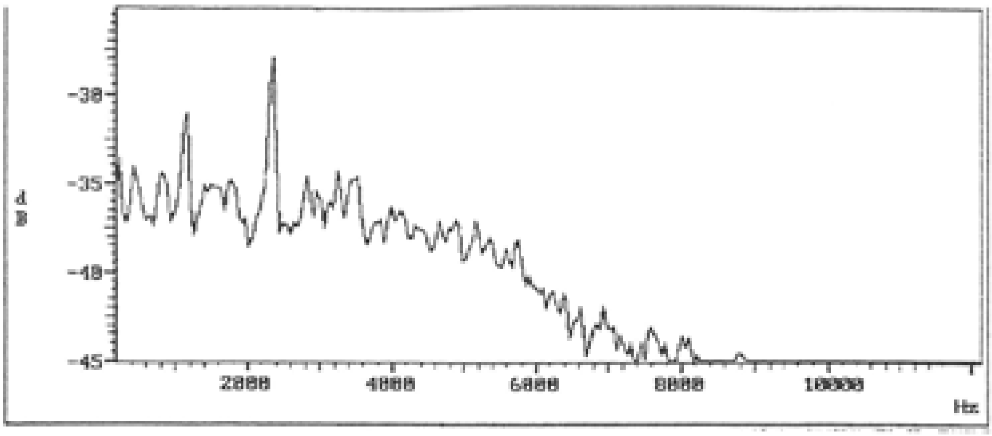
$$\text{Source level (dB)} = \text{Received level (dB)} + 20\log_{10} r \qquad r = 50 \text{ metres}$$

This does not allow for transmission losses due to absorption but these are negligible for the frequencies of interest at these distances (e.g., 0.01 dB for 4 kHz at 50 metres).

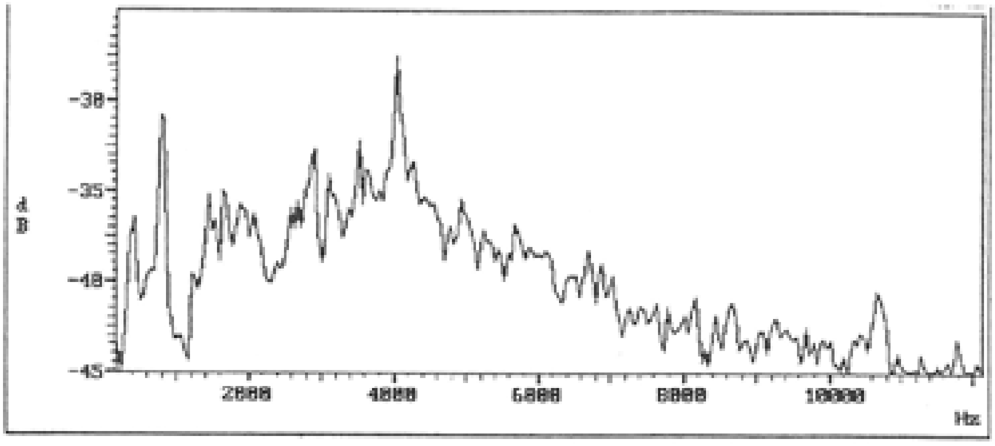
A2. Results and Discussion

A2.1 Boats.

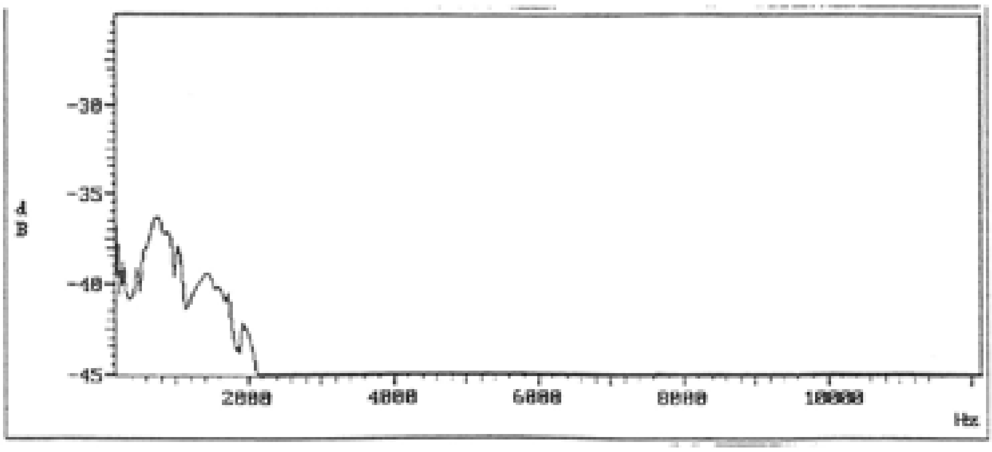
Power spectra for some of the trials are shown in Figure A1. For all the vessels the amplitude decreased rapidly above 12 kHz. Values below 200 Hz are not shown because of the problems encountered in recording and calibrating the equipment at lower frequencies. Several of the boats, notably *Challenger* had signatures with large low frequency components but because the trials were conducted over several days under different wind and swell conditions it was impossible to make accurate comparisons below 200 Hz.



Uruao. **Engine speed: 4200 rpm.**

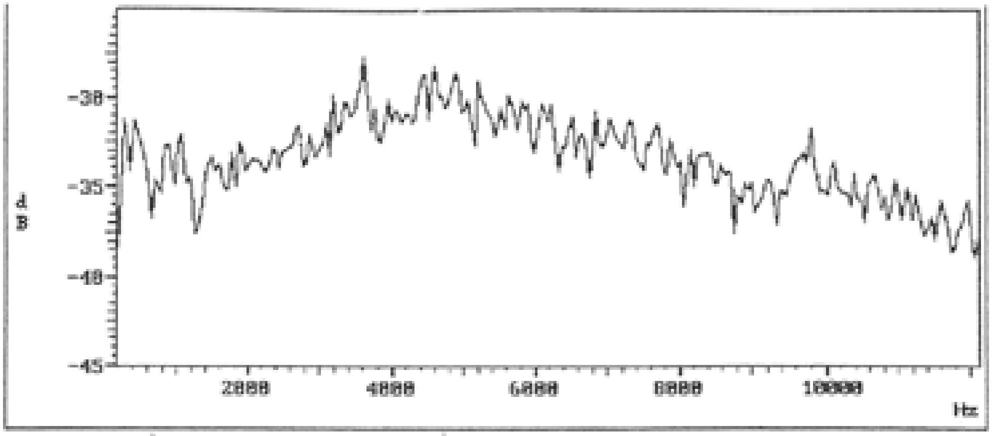


Tohora. **Engine: Half trim, full speed.**

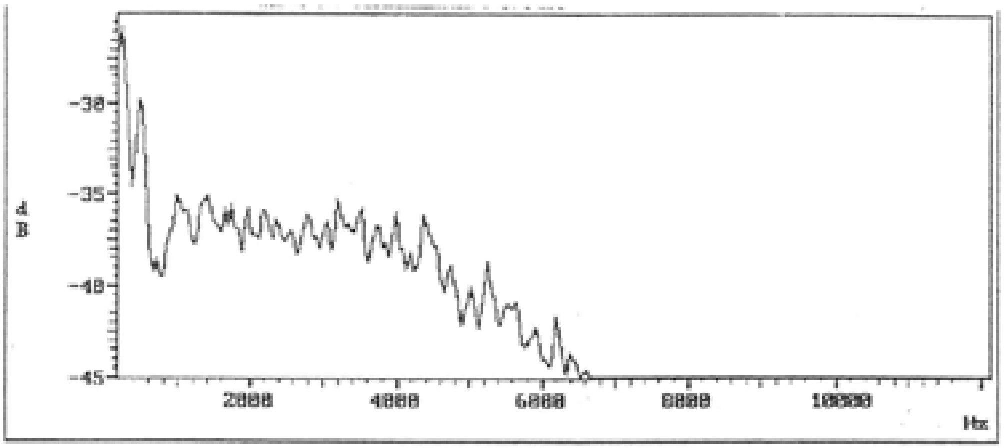


Challenger. Engine speed: 2750 rpm.

Figure A1 Spectrograms of boat noise in trials off Kaikoura.



Dolphin Encounter. Engine speed 3400 rpm.



Fine Catch. Engine speed: 3400 rpm.

Figure A1 cont. **Spectrograms of boat noise recorded in trials off Kaikoura.** **Note.** 0 dB corresponds to a source level of 153 dB re 1uPa at a range of 1 metre, at 1 kHz.

The results of the trials are shown in Table A1. The range R is calculated at which the received sound level would be at 0 dB relative to background noise assuming sea state 1 (wind 1-3 knots, wave height 0.1 metre). This was calculated using the transmission loss equation:

$$\text{Received sound level} = \text{Source level} - 20\log r - \alpha r$$

where α is the attenuation coefficient in dB per metre and r is the range in metres. Urick, (1975) gives the following approximate values for α and background noise levels (from Knudsen curves) for various frequencies.

Frequency	α **x10^{-3}**	**Background noise (sea state 1)** **dB re 1uPa**
250 Hz	0.01	60
500 Hz	0.02	58
1000	0.05	56
1500	0.1	54
3000	0.15	48
6000	0.3	43

Such calm conditions as sea state one are rarely encountered off Kaikoura. However, the calculated values of R are consistent with our estimates of the ranges at which we could detect boats under calm conditions when monitoring the hydrophones aurally. Distant boats at high speed were heard as a high pitch whine. The higher frequency components of boat noise were detected at greater ranges because of the reduction in background noise with increasing frequency despite the fact that higher frequencies suffer more attenuation.

The received sound level for a whale at depth of a noise source at the surface is difficult to predict because of the complex factors affecting sound propagation in the ocean. In the absence of absorption and refraction, noise levels from sound generated by wind or waves at the ocean surface would not vary with depth. The values of α shown above can be used to predict losses due to absorption but the effects of refraction are far more difficult to predict.

Urick, (1975) reports spectrum levels in deep water at frequencies above 500 Hz as being between 5 and 10 dB lower than those predicted by "classic" Knudsen curves derived from measurements close to the surface. Thus it is very likely that, for any given distance between the whale and boat, the received level of boat noise relative to background received by a whale at depth is also between 5 and 10 dB more than at the surface.

This would make an appreciable difference to the range R at which the received sound level was 0 dB relative to background. For example, for the 6 metre Naiad at full speed and maximum tilt R=8.5 km. If background noise at depth was reduced by 5 dB this would increase R to 14 km, while a 10 dB reduction would increase R to 21 km.

Table Al. Summary of boat noise trials.

Boat name and description	Engine revs. r.p.m.	Peak frequency Hz	Source level dB re 1uPa/Hz	R km
Uruao 12.6 m Naiad twin 250 hp outboards.	Almost full speed 4800	2700	126.3	7.4
	Cruising speed 4200	2300	125.2	5.4
	2000	1400	118.7	1.8
	1500	300	111.9	0.6
	single engine 1500	800	109.3	0.6
Tobora 6 m Naiad twin 140 hp outboards.	Full speed max tilt Approx. 5000	4000	125.5	8.5
	half trim Approx. 5000	4000	125.3	8.3
	motors down Approx. 5000	1500	126.2	(8.5)
	4200	3000	117.1	2.9
	3000	2700	116.1	2.3
	1500	1500	115.2	1.3
	single engine 1500	1500	110.9	0.8
Challenger 11 m single planing hull jet drive.	Full speed 2750	900	116.9	1.1
	2600	500	115.5	1.0
	1600	800	115.0	0.9
Dolphin Encounter 10 m Wildcat catamaran Volvo outdrive with duoprop.	Full speed 3800	500	128.9	(9.5)
	Cruising speed 3500	3600	126.3	8.7
	1300	800	109.2	0.6
Fine Catch catamaran with duprop outdrive.	Cruising speed 3400	250	126.8	2.3

R= Range at which received sound level at surface will be 0dB relative to background noise for Knudsen sea state 1.
R values in () indicate that the frequency at which the peak amplitude occurred does not correspond to the maximum range at which noise will be at 0 dB relative to the background.

Boat noise can be divided into three categories, machinery noise, propeller noise and hydrodynamic noise. For fast, light displacement boats the major source of noise is propeller noise, a large part of which is caused by cavitation. The amount of cavitation depends on the propeller design and depth below the surface in addition to speed of rotation. Fast light displacement boats are especially susceptible to cavitation because of their lively motion which often results in the propeller breaking the surface.

The results presented in Table A1 do not cover a wide enough range of conditions to allow a comprehensive comparison between types of engine or hull arrangement; however they are useful in assessing the level of noise to which whales were exposed during this study. Noise output can be affected dramatically by factors such as the condition of the propeller. For instance *Dolphin Encounter* and *Fine Catch* both have very similar engine/hull configurations but the noise spectra were very different. This was probably due to the poor condition of the *Dolphin Encounter's* propeller which may account for the almost continuous spectrum and amount of high frequency noise.

A2.2 Aircraft

We are not able to quote realistic figures for noise from either helicopters or planes due to the low received level at the hydrophone. Malme *et al.* (1982) concluded that the received underwater sound from an aircraft flying overhead is significantly lower (by approximately 20 dB) than that from a small fast boat at 100 metres. Sound waves travelling in air which intercept the sea surface at shallow angles will be almost totally reflected. The angle depends on the condition of the sea surface but almost complete reflection is likely to occur at angles of less than 45°.

Thus aircraft noise underwater will be at a maximum when the aircraft is directly overhead and no noise will be heard where the angle between the aircraft and horizon is less than 45°. There is very little change in underwater noise level with altitude because even though the received sound level at the surface decreases with aircraft altitude the cone of sound that intercepts the water surface increases in proportion.

APPENDIX *2*

SOME COMMENTS ON THE FUTURE DEVELOPMENT OF WHALE-WATCHING.

B1. Appropriate Vessels for Whale Watching

The special problems of working at Kaikoura place constraints on the type and size of boat which can be used. However, the industry would probably be improved by employing larger more comfortable vessels. The commissioning of the 12.6 metre vessel Uruao is a move in this direction.

Some increase in capacity of the industry can also be achieved by employing larger vessels, and unless these boats prove to be more disruptive than smaller ones, this should be the best way of expanding the industry without increasing disturbance. The relatively low source levels of the jet drive powered vessel *Challenger,* suggests that the use of this type of vessel should be investigated further.

Boats with similar noise characteristics may be expected to disturb whales equally, regardless of the number of passengers on board. It is clearly desirable, therefore, for boats to be full and for only the number of boats required for the passengers available to be sent out on each trip.

B2. Operation of the Industry

The way that the industry operates at the moment concentrates the majority of attention on a small number of apparently more tolerant individuals. In terms of minimising whale disturbance, there are advantages and disadvantages in this situation. On the negative side some whales are receiving a great deal of attention and though they seem to be tolerant, this study has revealed that tour boats do cause measurable changes in their behaviour. On the positive side, this disturbance would certainly not appear to be severe enough to drive these whales out of the area, and the majority of the population, which seems to include whales which are more susceptible to being disturbed, are less likely to be visited by boats.

Current evidence is not strong enough to suggest that whale watching operators should be discouraged from their current practice, but the large proportion of the surfacings of some whales for which boats are present is a cause for concern and the situation should continue to be monitored. Whale watching operators utilising other areas than those currently used would need to be carefully monitored in case whales in these areas proved more susceptible to disturbance.

The current practice, of a small fleet of vessels leaving South Bay at the same time, seems desirable for a number of reasons. This study revealed no increase in effect on surface behaviour with the number of boats present, so several boats on a single whale probably results in less disturbance overall than the same number of boats on several different whales. The boats can probably find whales more effectively together and can help each other in the event of breakdown.

Directional hydrophones have proved most useful in increasing the efficiency of the industry and in reducing disturbance to whales. The current design works adequately but it is likely that hydrophones with a better performance could be designed. It is important that any new operators entering the industry have easy access to directional hydrophones or to designs and instruction for their construction.

Sharing of information on whale positions and behaviour, both between boats and between boats and aircraft increases the efficiency of both operations and may decrease the risk of disturbance by boats. The present informal arrangements work adequately but might break down if rival groups were in competition. A requirement to report locations promptly to a central agency would ensure that this information was freely available and provide useful data for research.

The guidelines for conducting whale-watching proposed by MacGibbon (1991) and adopted by DOC would seem to have been successful in reducing whale disturbance while allowing the industry to operate effectively. There is scope for achieving further improvements by encouraging a more rigorous and consistent adherence to these regulations.

B3. Further Research

Research should continue on the possible disruptive effects of whale watching, especially as the industry evolves and new boats or activities are introduced. Attempts have not been made to measure any long term effects of whale watching and research which addresses this would be particularly valuable. Some useful data can be collected automatically from whale watching vessels. (For example whale watch boat movements and the positions of encounters with whales could be logged by a GPS navigator interfaced to a pocket computer). Other useful data could be collected by independent researchers from whale watching platforms.

Observations from the air will be important for measuring undisturbed behaviour. The whale watching industry could also provide opportunities to conduct research of general and scientific interest. By increasing public interest in sperm whales, this will in turn serve to promote whale watching.