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CONTENTS

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by

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ABSTRACT

The behaviour of sperm whales on the surface, and the vocalisations they made under water were analysed to investigate the possibility that whales were being disturbed by whale-watching operations off Kaikoura, New Zealand. Most visual and acoustic behavioral parameters were found to be highly variable between individual whales or types of whales and some varied with location. There seemed to be two distinct categories of whales. Some appeared to be resident along the break of the continental shelf and seemed to be more tolerant of whale-watching vessels. Some of these individuals received a great deal of attention from whale-watchers. Other whales appeared to be passing through the area and were less tolerant of whale-watching vessels. When whale watching vessels were present, the "non-resident" whales spent shorter periods on the surface, and had shorter ventilation intervals. Serial data for "resident" whales showed that they had shorter surface times and a lower number of ventilations when boats were present, and parameters describing the first bout of clicking after diving were also significantly different. In addition, whales were occasionally clearly disturbed by insensitive boat handling. There has probably been a substantial improvement in this aspect of watching in recent years and further improvements could be achieved by encouraging operators to adhere strictly to the current regulations. The possible biological significance of these changes in behaviour are discussed.

SUMMARY

The possible disturbance of sperm whales *(Physeter macrocephalus)* by whale watching vessels operating off Kaikoura, New Zealand, was investigated by comparing the surface behaviour and vocalisations of sperm whales in the presence and absence of whale watching vessels.

Observations and recordings were made from a small, quiet, independent study vessel. Sperm whale vocalisations were used as an indicator of their underwater behaviour. During 40 days at sea data were collected from 272 encounters. Whale watching boats were present for 72 of these.

The Kaikoura whale watching operation uses small, high speed, outboard-driven rigid-hulled inflatables. These produce high levels of underwater sound at frequencies between 2 and 4 kHz as was confirmed by underwater noise measurements of whale watching boats and other locally available vessels.

The values of most visual and acoustic parameters during encounters when no whale watching vessels were present, varied significantly between different individual whales and some also varied between offshore and inshore areas. The probability of whale watching boats being present also varied between zones and between whales, so that these effects had to be controlled for in any investigation of the effects of whale watching boats.

There appeared to be two categories of whales. A few tolerant individuals were "resident" along the edge of the continental shelf. They seemed to be tolerant of whale watching boats, were often known as individuals by the whale watching skippers and received a lot of attention from whale watching vessels. One of these, "White Dot", was with whale watching boats on over 1/3 of all observed encounters.

On some occasions sperm whales were clearly disturbed by the activities of whale watching boats. Typically these boats were not following whale-watching guidelines and the disturbance could have been avoided. This often resulted in whales diving without fluking up and this may have occurred on up to 10% of encounters with boats present.

It is likely that there has been a substantial reduction in such conspicuous disturbance since a previous report, MacGibbon (1991). The recent introduction of directional hydrophones for finding whales may have facilitated this.

In addition to such overt disruption, there were some other significant differences in parameters summarising surface behaviour which correlated with the presence of whale watching boats. Non-resident, "unidentified" whales had significantly shorter surface times, and shorter blow intervals when boats were present. Identified "resident" whales generally did not show significant differences in surface parameters. The finding that one identified whale showed significantly longer dive times after encounters with whale watching boats would seem to be an isolated and anomalous result.

There were no significant effects due to the presence of boats on acoustic parameters. Once boats were present within a certain range there were no additional significant effects due to the number of boats at or within 450 metres or 50 metres, or to the positions relative to whales, of boats at or within 50 metres.

The most powerful data for investigating the effects of boats were serial data collected from encounters with boats present and those before and/or after these encounters, because in these cases the effects of individuals and location were completely controlled for. Such data were only collected from identified "resident" whales and indicted that surface times were shorter and number of blows were lower for boat encounters than for the subsequent no-boat encounters.

A number of acoustic parameters summarising the first bout of clicking were also different between encounters with boats present and the previous encounter with no boats. Thus there are effects on the behaviour of even the seemingly tolerant "resident" whales.

The aircraft operating whale watching trips during the study did not appear to affect the whales directly, but their presence did affect the data collected by making it easier for the researchers and the whale watchers to spot whales when they came to the surface, and possibly also by making it more likely that resting whales would be encountered.

The effects of disturbance on surface behaviour seem to be relatively undramatic and effects on acoustic behaviour would seem to be restricted to the period directly after fluke up. However it may be premature to assume that these effects have little biological significance. In particular it should be noted that there have been no measurements of the long term effects of disturbance on these whales.

The whale watching industry in Kaikoura would seem to have reduced its disturbance of whales by following recommendations and guidelines made in a previous report (MacGbbon,1991). There is certainly still scope for improvements which can probably be achieved by encouraging a stricter and consistent adherence to the existing regulations.

1. INTRODUCTION

1.1 Sperm Whales in New Zealand

Sperm whales have been commercially exploited off New Zealand by a number of whaling operations: yankee whalers in the 19th century, by Japanese and Russian pelagic fleets during this century and by New Zealand shore-based whalers up to the early 1960's. Gaskin (1973) has summarised information on the distribution of sperm whales in the western South Pacific using data from these sources while research conducted in conjunction with the land-based whaling operation has resulted in a number of useful papers on the biology of sperm whales in the region (e.g. Gaskin, 1964; Gaskin, 1970; Gaskin, 1971; Gasldn and Cawthorn, 1967).

Sperm whales are found in New Zealand's waters throughout the year. Those encountered off the South Island of New Zealand, by both the shore-based whalers and by today's whale-watching operators, are mostly young adult and mature males measuring 12 to 16 m (Gaskin, 1968; Todd, 1991). Such whales are typically solitary or found in small groups (Best, 1979). The more social females and young frequent warmer waters and in this region their relative abundance falls off rapidly south of 44° S (Gaskin, 1973). Pelagic expeditions in the spring months made large catches of females between South Island and the Chatham Islands (Gaskin, 1973). This suggests that there may be a higher proportion of females in offshore waters.

The mixing of the Canterbury, East Cape and D'Urville currents, and upwelling of Antarctic waters along the N.E. coast of South Island makes this an area of very high productivity and a favoured feeding ground for sperm whales (Gaskin and Cawthorn, 1967). Extensions of the deep Hikurangi Trench push in towards the coast south of the Kaikoura peninsula and into the eastern end of the Cook Strait. Both of these features were known to be areas where sperm whales congregated (Gaskin and Cawthorn, 1967). Off the Kaikoura peninsula depths in excess of 1000 metres are found within a few miles of the shore. As a result, Kaikoura is one of the few places in the world where significant numbers of sperm whales can be reliably encountered so close to the shore.

Much has recently been learnt about the behaviour of individual whales in the Kaikoura region as the result of observations made by whale watchers (Todd, 1991; R Oliver pers. comm) and by those studying the effects of whale watching on whales (MacGibbon, 1991). Certain whales appear to be resident off Kaikoura for several months at a time and some have returned each year for up to four years. These "resident" whales have often been found to be particularly predictable in their location and to be tolerant of boats. Such whales have tended to receive the majority of the attention of whale watching vessels.

Of particular significance to the whale watch industry are seasonal changes in whale distribution. In the winter a few whales "take up residence" in a deep-water trench close to the shore, and close to the whale-watcher's base in South Bay. It is believed that they may be feeding on groper which spawn on the continental shelf at that time (Todd, 1991). Gaskin and Cawthorn (1967) only found groper in the stomachs of whales, caught between the end of April and the end of June, and with a body length of 14 m or over. In summer, whales are usually only found further offshore.
The whale watch operators know some whales as individuals who often exhibit very distinctive behaviours, and this has been confirmed quantitatively by the work of MacGibbon (1991).

1.2 Whale Watching from Kaikoura

Whale watching from Kaikoura was pioneered in 1988. An account of the history of the development of this industry and some indications of its economic significance are given by Scott (1991). Commercially, whale watching would seem to have been a great success, with four boats licensed for this activity, operating up to four trips per day. One of these boats has recently been replaced by a much larger vessel which will increase the operation's capacity. Additional larger boats are planned for the future. Two light aeroplanes and a helicopter were also running whale watching trips in the summer of 1992.

The significance to the local economy is substantial. The tourists who visit Kaikoura to go whale watching spend money in many other local businesses including hotels, restaurants, and souvenir shops so that the benefit to the community is widely felt. On a national level whale watching appears to have joined jet-boating and bungy-jumping as a tourist attraction which typifies the exciting, outdoor, "Green" image for which New Zealand is famous.

If conducted properly whale watching has an important role to play in raising public awareness and in education. Whale watching provides an enthused captive audience and an opportunity to interest ordinary members of the public in marine mammals, other wildlife and conservation issues.

1.3 Potential for Disturbance

Whale watching operations are already well established in several parts of the world, particularly in the USA. An ongoing concern has been that if not pursued sensitively, whale watching will result in an unacceptable and harmful level of disturbance to the whales. It has been recognised that harassment could have both short-term and long-term effects for humpback whales in Hawaii (Norris and Reeves, 1978). Short-term effects would include behaviours such as avoidance and aggressive behaviour possibly resulting in short-term stress. Long-term effects of harassment on critical behaviours such as feeding, resting, and mating could result in a reduction in the biological fitness of a population.

In practical terms it is feasible to measure short-term changes in behaviour which correlate with potential sources of disturbance. However the significance of these and how they may affect the fitness of individuals in the longer-term is generally a matter of judgement. It is extremely difficult to measure the long-term effects on population viability of any particular source of disturbance.

The 1990 New Zealand Marine Mammal Protection Regulations define harassment as:

"including any act that
a) causes or is likely to cause injury or distress to any marine mammal;
b) disrupts significantly or is likely to disrupt significantly the normal behavioral patterns of any marine mammal."

Some of the conditions governing commercial operations include:

- no vessel or aircraft shall be operated so as to disrupt the normal movement or behaviour of any marine mammal
- contact with any marine mammal shall be abandoned at any sign of it becoming disturbed or alarmed
- no person shall make any loud or disturbing noise near any marine mammal
- no aircraft or helicopter shall operate at a distance less than 300 metres from any marine mammal

- no person shall be less than 50 metres from any whale other than a stranded whale
- a vessel shall approach a marine mammal from a direction that is parallel to the mammal and slightly to the rear of the mammal
- any vessel less than 300 metres from any marine mammal shall move at a constant slow speed no faster than the slowest marine mammal in the vicinity, or at "idle" or "no wake" speed
- no sudden or repeated change in speed or direction of any vessel shall be made, except in the case of an emergency

The Department of Conservation (DoC) has been concerned that whale watching in New Zealand should be conducted to a high standard and be regulated to avoid some of the problems which have arisen in other areas. Whale watch operators have to obtain a permit and are required to follow a set of guidelines designed to minimise disturbance (see some of these above).

Sperm whales have rarely been the subjects of whale watching in other areas and there have been no previous studies into the effects of vessel disturbance on their behaviour. The small high-speed rigid-hulled inflatables, used off Kaikoura, are also not widely used by whale watching operations in other parts of the world and generate high levels of underwater noise. Sperm whales are believed to echolocate like other odontocetes, and hence there is the additional concern that boat noise could interfere with this vital sensory modality.

In 1990, DoC commissioned a study of behavioral responses of sperm whales to whale watching vessels (MacGibbon, 1991). Some behavioral parameters were modified by the activities of whale watching boats. In particular, surface intervals decreased and respiratory intervals were shorter when boats were present. In the presence of boats, whales were also more likely to dive quickly without raising their flukes, to make short dives and behave more erratically on the surface. Certain boat operations including rapid approaches, sudden changes of speed or gear and close approach to the animal, particularly to its head, had marked effects. MacGibbon made a number of recommendations including guidelines for more sensitive boat handling, increased use of hydrophones to position boats close to surfacing whales, exploring the use of alternative types of craft and the need for further research.

Feeding sperm whales spend over 3/4 of their time underwater (Gordon and Steiner, 1992) and it is here, well away from the surface, that one of their most significant activities, feeding, takes place. It is therefore clearly important to investigate whether or not the activities of whale watching vessels are affecting the underwater behaviour of sperm whales. Whales can not be directly observed during these dives and packages and techniques for electronically logging their behaviour are not yet well developed. However feeding sperm whales are vocal for most of the time that they are underwater. They make a number of distinctive vocalisations which are probably a form of echolocation (see Section 1.6) and which can be readily monitored and recorded from a boat at the surface. These vocalisations are thus the most accessible index of their underwater behaviour available for analysis.

1.4 Previous Studies of the Effects of Underwater Noise on Large Whales

Watkins, *et al.* (1985), made observations of sperm whales in the Caribbean during periods of intense military sonar activity. Several kinds of sonar signals were heard with frequencies ranging from 3250 to 8400 Hz in pulses of 0.145 to 0.45 seconds duration. They noted that whales subjected to loud sonar sequences immediately fell silent and often appeared to break off from their activities, scatter and to move away. Periods of silence were longer in response to higher levels of sound signalling. Later in the same area, when only one short sequence of military sonar was heard, the whales responded by falling silent but returned to normal activity within an hour. The same authors observed that sperm whales did not appear to be disturbed by sonar signals of frequencies above 35 kHz but that they did react to a 12 kHz pinger, engine starting noise and banging the ship's hull

Other studies have investigated the effects of exposure to high levels of noise in other species of great whale. Malme *et al.* (1987) observed that Gray whales stopped feeding and moved away from an area in response to a seismic sound source (an underwater air gun). They noted an increase in the number of whales that reacted with increasing sound level Richardson et al (1986) observed no definite effects of seismic noise on bowhead whale behaviour.

In a study of the effects of vessel noise on humpback whales summering in Alaska, Baker and Herman (1989), demonstrated a number of significant responses including decreases in breathing intervals, increases in dive times and orientation away from the path of moving boats, often at ranges of up to 3-4 km

1.5 Typical Patterns of Sperm Whale Surface Behaviour

Feeding sperm whales behave in a fairly predictable fashion. They make long deep dives (which may take them to over 1000 m) interspersed with periods spent breathing at the surface in preparation for the next dive. Typically they move only slowly during these surface bouts. They seem intent on recovering from their last dive and preparing for the next one as quickly as possible, and exhibit a limited repertoire of behaviours. Usually they end their period at the surface by raising their tail-flukes above the surface of the water (fluking up) to initiate their near-vertical dives.

Gordon and Steiner (1992) presented data on dive cycles and blow rates observed from whales in the Azores. Average dive times for sperm whales feeding in the Azores were 55 minutes with average surface times being about 11 minutes. Average blow intervals were 12.0 seconds for females and small males and 18.2 seconds for large males. Blow rate was also shown to change during a surfacing. Whales blew at a high rate when they first surfaced but this declined through the surfacing, increasing again just before fluke up.

Female sperm whales and young males, which usually associate in stable schools of about 25 individuals, typically cease feeding and come together to "socialise" for a few hours about once a day before dispersing to continue feeding (Gordon, 1987; Whitehead, 1989). Large males have also been seen resting at the surface for long periods (Todd, 1991; Gordon pers. obs in Azores).

1.6 Sperm Whale Acoustic Behaviour

Sperm whales live in a medium which transmits light very poorly and feed at depths to which little or no sunlight penetrates. By contrast seawater transmits sound very well, in fact sound propagates through water more efficiently than any other form of radiation (Urick, 1975). It is not surprising therefore, that sperm whales are highly vocal animals seeming to make vocalisations of one form or another for most of their lives. They probably use these sounds to find their prey, to navigate underwater, and to communicate.

Sperm whales only make impulsive "click vocalisations" (Watkins, 1980) but these can be qualitatively different and can be made in a number of distinctive patterns.

A. Regular Clicks

Sperm whales emit long sequences of loud clicks at fairly regular rates typically between one and two per second. Bouts of regular clicking are interspersed with short silences and "creak" vocalisations (described later).

"Regular" clicks have frequencies ranging from less than 100 Hz to over 30 kHz, and within this range there are certain emphasised frequencies. Emphasised frequencies can vary from whale to whale and even between clicks in a sequence. Higher frequencies are attenuated more by sea water than lower ones. Thus, Watkins (1980) reported that, in recordings from whales at close range, higher frequencies (10-16 kHz) were emphasised while, in recordings of more distant whales, the emphasised frequencies were around 4 kHz. Source levels measured for sperm whale "regular clicks" have ranged as high as 180 dB re luPa (Watkins, 1980). Using fairly simple acoustic equipment, such as that deployed during this study, regularly clicking sperm whales can be heard at ranges of up to 5 miles (Leaper *et al.*, 1992).

After a whale has fluked, both the whale's clicks, and their echoes returning from the sea bottom (1000 or more metres away) can often be clearly distinguished. In these cases it can be determined that sperm whales click soon after receiving the echo from the bottom

B. Creaks

"Creaks" are rapid sequences of clicks, produced at rates of up to 220 per second, and lasting for 10-25 s. Click rate usually increased during creaks. Creaks are typically made during long sequences of regular clicks (Gordon, 1987). Creaks generally sound much quieter than regular clicks, which may be because they are more directional and are not projected towards the surface.

The pattern of click rate during a creak is similar to that during echolocation runs made by bats and dolphins as they close on targets (Griffin, 1958) and it has been proposed by Gordon (1987) and others that they are made by sperm whales investigating targets at close range and may indicate feeding attempts. Gordon (1987) presented some observations which support this proposal. He showed that when sperm whales were being tracked with an echo-sounder they often showed a distinct change in dive rate while creaking. This could be interpreted as the whale diverting to investigate an object. The rates at which clicks were made during creaks, and the rates at which click rate increased were appropriate for an echolocatiog sperm whale closing with a target.

Observations made by Ohlsohn (1991) during a detailed study of the vocal output of individual whales were also most easily interpreted if creaks are assumed to be echolocation runs associated with feeding. She found that the rate of regular clicking increased before creaks (as though the whale was approaching an object of interest). Creak rates were higher in the last 3/4 of a dive and were higher during longer dives. Feeding activity might be expected to be less during the initial travelling part of a sperm whale's dive, and longer dives (which are likely to be physiologically expensive) might only be expected to occur when feeding conditions are good.

The nature of creak vocalisations suggests that they are echolocation runs and various other observations are consistent with this. The link between creaks and such an important activity as feeding seems strong enough for special emphasis to be placed determining creak rates as an index of feeding activity, in a study of disturbance. Positive proof that creaks are associated with feeding does not exist and will be very difficult to obtain for such an intractable animal.

C. Rapid Clicks

Sequences of rapid clicks, at rates of 80 s^{-1}, are sometimes heard from sperm whales at the surface, often when whales seem to be investigating an object, such as a boat or swimmer (Norris and Harvey, 1972; Gordon, 1987). Gordon, (1987) found evidence that these clicks were projected directionally and the emphasised frequency within successive clicks changed in a regular way. They too would seem to be a form of echolocation.

D. Clangs

Clangs are very loud resonant clicks with a more limited range of frequency emphasis. They are typically heard in sequences with low but precise repetition rates (e.g. once every 7 s). Clangs are the same vocalisations as the "slow clicks" reported by Weilgart and Whitehead (1988). They reported that hearing "slow clicks" usually correlated with the appearance of large males in the social groups of females and young sperm whales.

However, clangs were first reported from Sri Lanka by Gordon (1987). Here they were often heard during the spring months even though no mature males were ever sighted In the Azores (Gordon, pers. obs.) clangs have only ever been attributed to large males at or near the surface. Ohlsohn (1991) reported that short sequences of clangs were often heard from single male sperm whales just before they came to the surface, and Mullins *et al,* (1988) heard "slow clicks" from a single large male at the surface.

E. Codas

Codas are distinctive and stereotyped patterns of clicks. They were first reported by Watkins and Schevill (1977) as occurring at the end of long sequences of regular clicks. However, they are most often heard from larger groups of socialising whales at the surface (Watkins *et al.,* 1985; Gordon, 1987; Weilgart, 1990). The function of codas is not known. They do not seem to act as individual identifiers as Watkins and Schevill (1977) originally proposed, but they may have some other role in acoustic communication.

Acoustics has also proved to be a very useful tool for studying sperm whales. Acoustic techniques have been used for finding and following sperm whales (Whitehead and Gordon, 1986), for assessing the size of populations (Leaper *et al,* 1992) and for measuring the length of sperm whales (Mohl *et al,* 1981; Gordon, 1989). As knowledge of sperm whale acoustic behaviour develops it is becoming possible to make inferences about their behaviour when they can't be seen (when it's dark or they are underwater) by listening to their vocalisations.

1.7 Aims of the Present Study

The aims of this study were to make observations of sperm whale surface behaviour, along similar lines to MacGibbon's investigation, with a particular view to determining the extent to which implementation of her recommendations had alleviated whale disturbance, and to investigate possible effects of whale watching on whales underwater through analysis of their acoustic behaviour. An emphasis on acoustics is also appropriate because in most cases it is likely that the whales are reacting to the sound generated underwater by whale watching vessels.

The terms of reference agreed by DoC were:-

1. To describe and quantify acoustic and surface behaviour of sperm whales in Kaikoura.

2. To assess changes in acoustic behaviour and surface behaviour in response to available potential whale watching vessels of a variety of sizes and hull/motor configurations.

3. To provide recommendations to the Department of Conservation on the most appropriate type of vessels and any necessary modifications to a code of practice of whale watching vessels.

4. To investigate the extent to which improved acoustic equipment fitted to whale watching vessels would enable whale watching operations to be less disruptive to whales and more informative to the public.

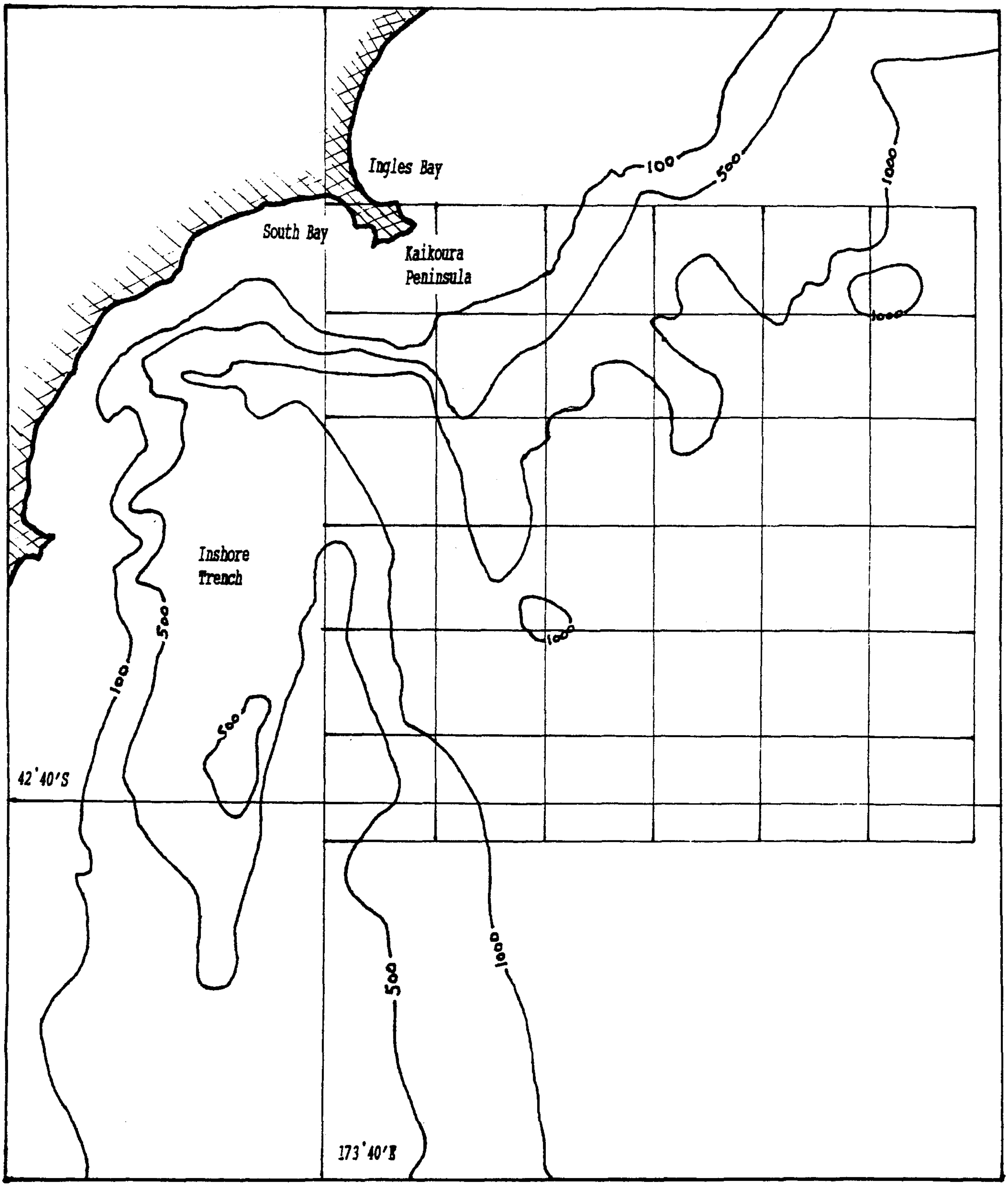


Figure 1 **Study area and the 6X6, five kilometre square grid used for statistical analysis. Depths are in metres.**

2. MATERIALS AND METHODS

2.1 Area and Period of Study

Whales were encountered within an area of about 700 square kilometres to the southeast of the Kaikoura peninsula (Figure 1). Most encounters with whales were within the usual area of operations of the whale watching vessels at this time of the year. This is similar to the study area of MacGibbon (1991) but extends further offshore and does not include the inshore canyon which some whales use in the winter.

Fieldwork was carried out between 8 January 1992 and 9 March 1992. During this time 40 days were spent at sea in weather conditions suitable for data collection. Good data were collected for 272 encounters, on 72 of these occasions whale watching boats were present.

2.2 Study Vessel

The vessel used throughout the study was the 8 metre sloop, *Rangatahi,* powered by a Volvo MD2-B two cylinder, 25 hp diesel engine with a three bladed propeller. This gave a maximum speed of about 6 knots. The sailing ability of *Rangatahi* was too poor (with the sails and rig available) to allow whales to be tracked under sail as had originally been planned. Generally the sails were only used to steady the vessel.

To minimise disturbance and to allow extended recordings to be made the boat was operated at low speed (2-3 knots) when with whales. At this speed the noise of the engine and propeller were barely audible on the hydrophones being towed behind the boat. We also endeavoured to keep at least 300 m from any whales on the surface.

A Magnavox MX1000 GPS was used for determining the boat's position and this was stored on an Amstrad ALT laptop computer every minute using the "Wayplanner" navigation software package.

2.3 Acoustic Equipment

The hydrophone used for monitoring and recording was a towed unit (Leaper, *et al.*, 1992). This consisted of two hydrophone elements (Benthos AQ-4) connected to low-noise pre-amplifiers, with a 30 dB gain and 200 Hz high-pass filter, mounted in a 12 m long, 30 mm diameter oil-filled polythene tube; this was towed on 100 m of cable behind the boat. The unit's streamlined nature and the long tow-cable meant that hydrophones could be monitored, and recordings could be made, while the boat was moving. Signals from the hydrophones were amplified by a custom built, variable gain amplifier with 21 kHz low-pass filter and recorded on a Digital Audio Tape recorder (Sony TCD 10-Pro).

A directional hydrophone was used to obtain bearings to vocalising whales. This consisted of ten evenly spaced hydrophone elements connected in parallel, and mounted in a one metre long, 11 cm diameter, plastic tube which was acoustically shielded with closed cell foam on one side. This plastic tube was mounted horizontally on the end of a vertical steel pole which was fixed to the stem of the boat in a way which allowed the hydrophone to be to be lowered into the water and rotated to obtain a bearing, or raised when the boat was under way.

2.4 Daily Routine

The study vessel usually left Kaikoura wharf in Ingles Bay by 0600 hours. The first visual encounter of the day was usually between 0800 and 1000. Data collection continued until about 1700 unless terminated by bad weather.

The early start and relatively early return home were necessary because of the distance which had to be travelled from Ingles Bay and the slow speed of the study vessel. During the summer, on-shore winds often increased through the day sometimes resulting in whale watching trips being cancelled and occasionally to data collection being abandoned.

Once the vessel was in waters over 500 metres deep the towed hydrophone was monitored every fifteen minutes until sperm whale vocalisations were heard, when the vessel would be hove to and the directional hydrophone lowered to obtain a bearing to the whale's vocalisations. The vessel would then move in that direction and the towed hydrophone would be monitored regularly by listening in stereo. This allowed the operator to determine whether the whale was ahead or astern. A new bearing was taken whenever the whale was no longer judged to be ahead. In this way the research vessel could be manoeuvred close to the position at which the whale would come to the surface after its dive.

Whenever possible whales were followed through dives using passive acoustic techniques. When this could be achieved, and tour boats happened to visit that whale during some of the encounters, data could be collected from the same individual for surfacings before and/or after encounters with tour boats present. (Whales were only considered to have been tracked in this way when they could be individually identified during each surfacing.) Such data were particularly valuable because they approximated to natural experiments, with such factors as whale identity and location remaining constant and only the presence of tour boats changing.

2.5 Collection of Visual Information

2.5.1 Recording surface behaviour. An encounter started when a whale was first seen and ended when data could no longer be collected from that whale. For visual data this was when the whale left the surface, for acoustic data this was when the whale's vocalisations could no longer be clearly distinguished from those of other whales.

Sperm whale surface behaviour and tour boat activities were logged directly into a hand-held computer (Psion OrganiserII) naming a specially written event-recording program. This allowed the time of occurrence (to the nearest second) of certain distinctive behaviours to be scored, as well as the activities of boats and aircraft. A separate data file was made for each encounter.

Data recorded from whales included the time of occurrence of such activities as blows, side-flukes, head-outs, dives without fluking and fluking up. The time of occurrence of a behaviour which lasted a finite time, such as a blow, was taken to be the time at which it was first seen. Whale directional headings were recorded when first seen, when fluking and at intervals during the surfacing. Range and bearing from the study vessel to the whale were also recorded.

Data on whale-watch boat activity included, number of boats at or within 450, 150 and 50 metres of the whale and the times at which these changed. 50 metres was chosen as the closest distance because it is the distance specified in the regulations. 450 metres seemed an appropriate outer limit, while 150 metres was the range at which the difference in amplitude between a sound at 50 metres and 450 metres is halved. (in terms of amplitude it is half way between 450 and 50)

The relative positions of boats at or within 50 metres were recorded by assigning each to one of six 60° sectors around the whale. The presence of aeroplanes and helicopters was also noted. When conditions allowed, encounters with whale watch vessels present were recorded on video which was synchronised with underwater recordings.

Sperm whales are difficult to see at sea and it was not always possible to be confident that a whale had been spotted as soon as it came to the surface. Thus, observed surface times would usually be lower than actual surface times. When whales were sighted as soon as they came to the surface a note was made of the number of blows which had occurred before event recording began. This allowed a correction to be made for these missed blows and the real surface time to be determined accurately. Otherwise encounters were classified as being either "early", if it was believed that the whale had been seen soon after it reached the surface (for example if it was first sighted close to the boat and in an area which had been well watched) or "unknown" if this was not the case.

2.5.2 Individual identification. Photographs were taken of whales' flukes, flanks and dorsal fins to enable individuals to be identified. A Canon T90 was used with 300 mm, f4. lens and XP2 black and white film. Films were processed, printed and analyzed at a later date. The need to keep well away from whales, and to manoeuvre as little as possible while they were on the surface, in order to minimise disturbance to them, greatly hampered our ability to take useful photo-identification photographs. Some whales had very distinctive marks which could be spotted using binoculars in the field On some occasions the whale watching skippers, who knew some whales well and approached them much more closely than the study vessel, relayed the identity of whales by radio.

2.5.3 Range estimation. Ranges to whales and from whale-watching boats to whales were estimated by eye and logged by the event recording program. Estimating ranges by eye at sea is notoriously difficult. Ranges in this study can probably be reliably compared with each other but may not be absolutely accurate. The lack of a tall, sturdy mast and the large swell often encountered, precluded the use of the measuring technique described by Gordon (1987). A hand-held stereo range finder (Ranging 1200) was also tried, but proved impractical for use with moving subjects at sea in field conditions.

Rings of known dimensions (0.5 m diameter) were stuck to the sides of whale watching boats. Photographs were taken of these in the field using a 300 mm lens whose exact focal length was determined. Measuring the longest diameter of the ring on enlargements of these images allowed the range to boats to be calculated.

Stereo photography was also attempted for measuring range and the relative positions of boats and whales. However, this proved not to be feasible because of the requirement to keep the study vessel well away from the whales on the surface.

2.6 Analysis of Surface Behaviour

Files were transferred from the Psion Organiser to an IBM compatible laptop computer. Programs written in Turbo Basic were used to provide a graphical summary and to extract summary statistics from each encounter. These included mean and standard deviation of blow interval for each encounter, surface time, number of blows scored, whether or not an encounter ended with a fluke, the whale's heading when first seen and at fluke up, the number of boats present at different ranges and the positions of boats at or within 50 m of the whale.

The value of each blow interval and its order relative to fluke up were also stored (The last blow interval before fluke up would be 1, the interval before that 2, etc.) This allowed changes in blow interval throughout a surfacing to be investigated

When an individual whale was identified on successive surfacings, dive cycle parameters were calculated. These included fluke to fluke times (the elapsed time between two successive fluke-ups), estimated dive time (the difference between fluke to fluke time and surface time), dive distance (the distance between fluke positions for two successive encounters), and travel speed (dive distance / fluke to fluke time).

The position of each encounter was retrieved from the data stored automatically from the GPS Navigator at the time of the fluke up. For analytical purposes encounters were assigned to cells of a 6x6 grid of 5 km squares positioned south and east from 42° 25'S, 173° 40'E. Figure 1 shows this grid overlaid on a chart of the area. For each grid square the minimum and maximum water depth shown on the chart were noted. The grid squares were also assigned to one of two zones. "Shelf" if any of the area had a water depth less than 1000 metres and "Offshore" if the water depth was all greater than 1000 metres (Figure 2).

2.7 Collection of Acoustic Data

Recordings were made from the time of fluking for all whales for which visual data had been collected and were continued for a minimum of ten minutes or until the vocalisations of an individual could no longer be distinguished. Recordings were also made while the whale was on the surface for encounters where tour boats were present. Notes were made and the tape was indexed when any sounds of particular interest were heard. A total of 250 hours were spent in acoustic contact with whales. 150 hours of acoustic recordings were made onto DAT tape of which 46 hours were selected for analysis.

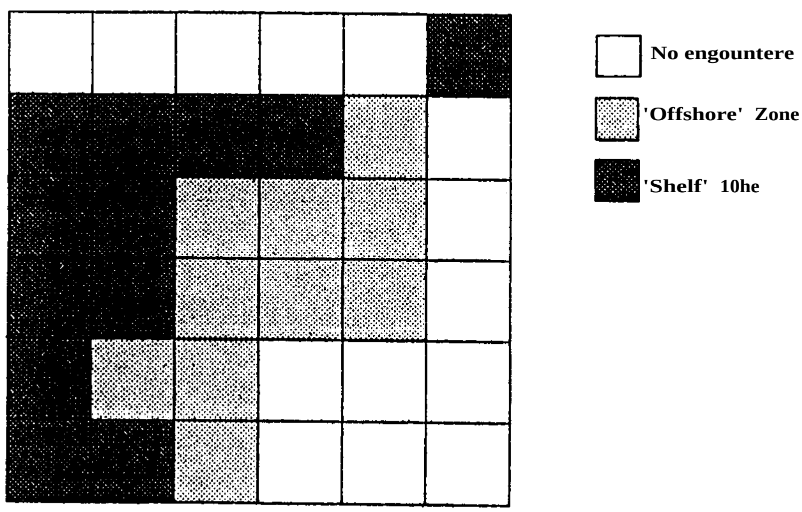


Figure 2 **Division of 5 Ion grid squares between "shelf' and "offshore zones.**

2.8 Analysis of Acoustic data

On play-back, recordings were carefully monitored aurally and played through a custom-built analogue trigger (see Leaper *et al,* 1992 for details) adjusted to trigger off clicks above a particular threshold level, i.e. the clicks of the whale which had just been encountered on the surface. The time of each triggering click was measured automatically by a Cambridge Electronic Design "1401 Laboratory interface" interfaced to a personal computer running a specially written Pascal program. Other vocalisations, such as creaks and trumpets, and the estimated strength of boat noise (on a scale of 0 to 5) were entered from the keyboard. All times were recorded with an accuracy of 0.05 s and were related to the time at which the whale fluked.

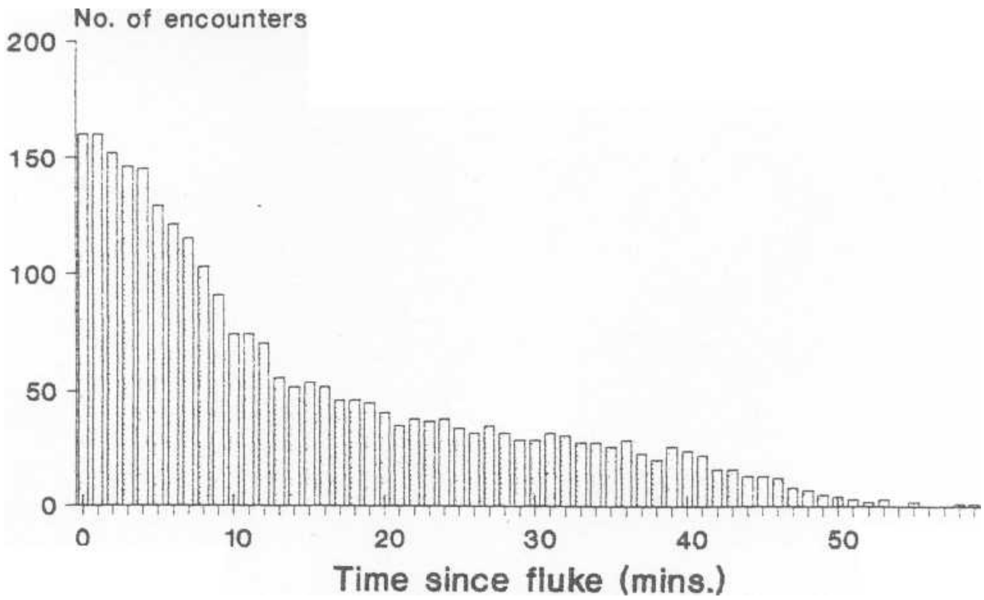
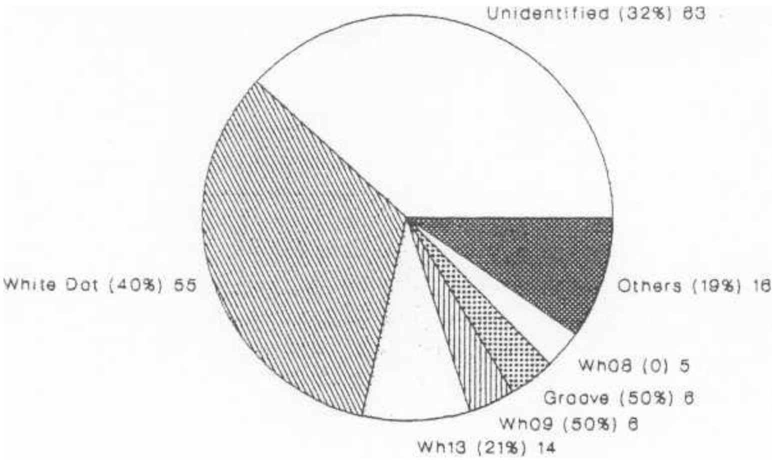


Figure 3 **Distribution of number of encounters with recordings of high enough quality to be usable for each minute after fluke up.**



Bracketed figures indicate % encounters with tour boats.

Others: Identified animals encountered on less than five occasions.

Figure 4 **Proportion of encounters with different identified individuals and unidentified whales.**

Data were omitted from the analysis if whale vocalisations were heard but could not be distinguished from background noise by the trigger circuit. Analysis of a recording ceased when it no longer became possible to distinguish the clicks of an individual from the vocalisations of other sperm whales. Throughout all analysis sessions a graphical output of interclick interval against time was displayed which enabled the operator to validate the data being collected. This was particularly useful in alerting the operator to any clicks that failed to trigger, or to sounds which falsely activated the trigger device.

Figure 3 shows the number of encounters with recordings where the automatic trigger system could be used reliably for each minute following fluke up. The number of encounters with usable recordings fell off rapidly with time from fluke, mainly because the subject's vocalisations became indistinguishable from those of other whales in the area. On half of the occasions over nine minutes of recordings could be analyzed and in some cases, data for entire dives were analyzed. The part of the dive most likely to have been affected by whale boats on the surface, that immediately after fluke up, received the most complete coverage.

The pie chart in Figure 4 shows the number of encounters for which acoustic data were analyzed from individually identified animals and the percentage of these encounters where one or more tour boats were present at the time of fluking.

2.8.1 Acoustic behaviour summary parameters. Several parameters summarizing sperm whale vocal behaviour and calculated for each encounter are defined below.

A. Parameters summarizing initial clicks

(a) Time from fluke to first clicks.

(b) Length of first bout of clicks. The bout was considered broken by a silence when the interclick interval was greater than five times the previous interclick interval.

(c) Duration of first silence.

(d) Initial mean interclick interval. The mean interclick interval between the first five clicks. Where clicks started with one or two resonant clicks with a large interval (e.g. clangs) these were not included when calculating the mean.

(e) Mean interclick interval at the end of first bout. The mean interclick interval between the five clicks immediately prior to the first silence.

(f) Change in interclick interval during first bout. The difference between *initial mean interclick interval* and *mean interclick interval at end of first bout.*

(g) Occurrence of "trumpets". The occurrence and time after fluke of "trumpets" was recorded

B. Parameters summarizing creaks

(a) Time from fluke to first creak

(b) Creak activity. This was defined as the number of creaks heard divided by the time for which data were analyzed after fluke.

(c) Creak rate from first creak The number of creaks heard divided by the time for which data were analyzed following the first creak.

C. Parameters summarizing interclick intervals

(a) Mean clicks per second. The total number of clicks heard divided by the time for which data were analyzed after fluke.
(b) Modal interclick interval. The modal interclick interval for all interclick intervals during the period of data analysis.
(c) Percentage of clicks with modal interclick interval. The number of modal intervals divided by the total number of interclick intervals.
(d) Sudden changes of click rate. Sudden changes in rate were recorded visually from plots of interclick interval against time following fluke.

2.8.2 Statistical analysis of visual and acoustic data. None of the data (with the exception of number of blows) were found to fit a normal distribution so non-parametric statistical tests were used. Statistical analysis was completed using the SPSS and Minitab packages.

Statistical tests of the effects due to a number of variables were conducted on certain subsets of the data to control for the effects of some other variables. Figure 5 shows the data used and factors compared for many of the statistical tests of surface and acoustic behaviour.

Data from those occasions when it was possible to compare data for encounters with tour boats present with that from surfacings of the same individual immediately before and/or after that encounter, were analyzed using Wilcoxson matched-pairs signed-rank tests.

3. RESULTS AND DISCUSSION

3.1 Activities of Whale Watching Vessels

During the study period only two companies, Kaikoura Tours Ltd and NZ Nature Watch Charters Ltd, had permits for whale watching. They operated four 6 metre Naiad rigid hulled inflatables, three of which were powered by twin 140 h.p. outboards, the other by twin 115 hp. outboards.

The use of such small fast boats partly reflects a requirement in the past to abide by regulations which would not allow larger vessels to be registered for this work, and is partly dictated by the special conditions in Kaikoura. There is no sheltered harbour in the Kaikoura area and boats based at South Bay (the bay closest to good whale areas) are pulled out of the water on trailers. The whale watching boats are pulled out between each trip. The requirement to be trailable limits the size of boats which can operate from South Bay. The powerful engines allow the whale watching boats to travel at speeds of 30 knots which enables them to get out to sea and find whales quickly. Vessels are able to utilise short periods of fine weather and are able to return quickly if the weather deteriorates unexpectedly.

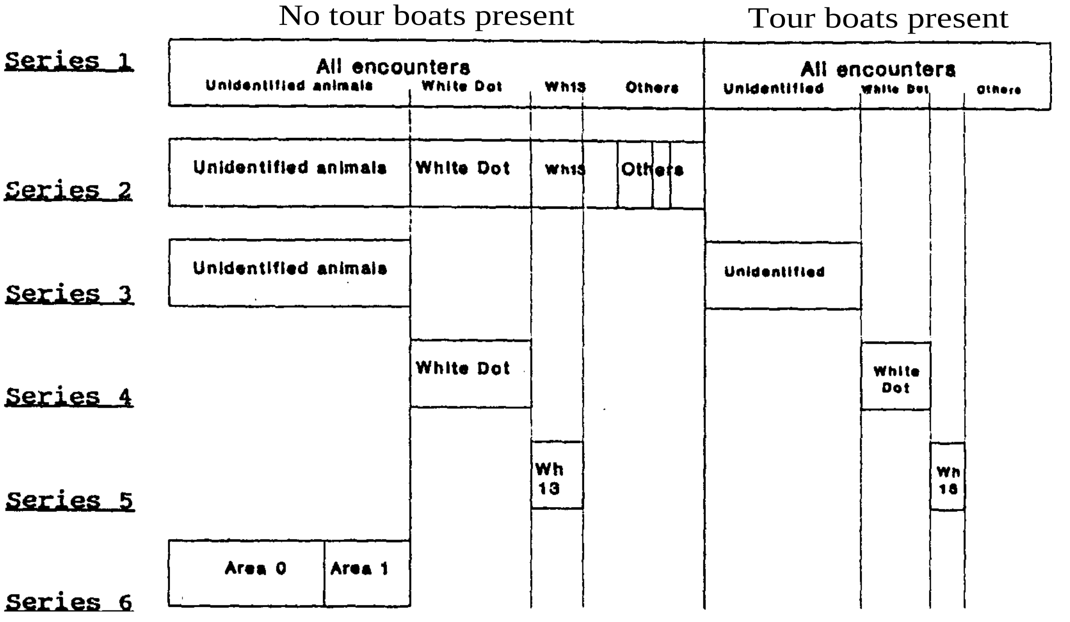


Figure 5 **Sub-divisions of data used for many series of statistical tests.**

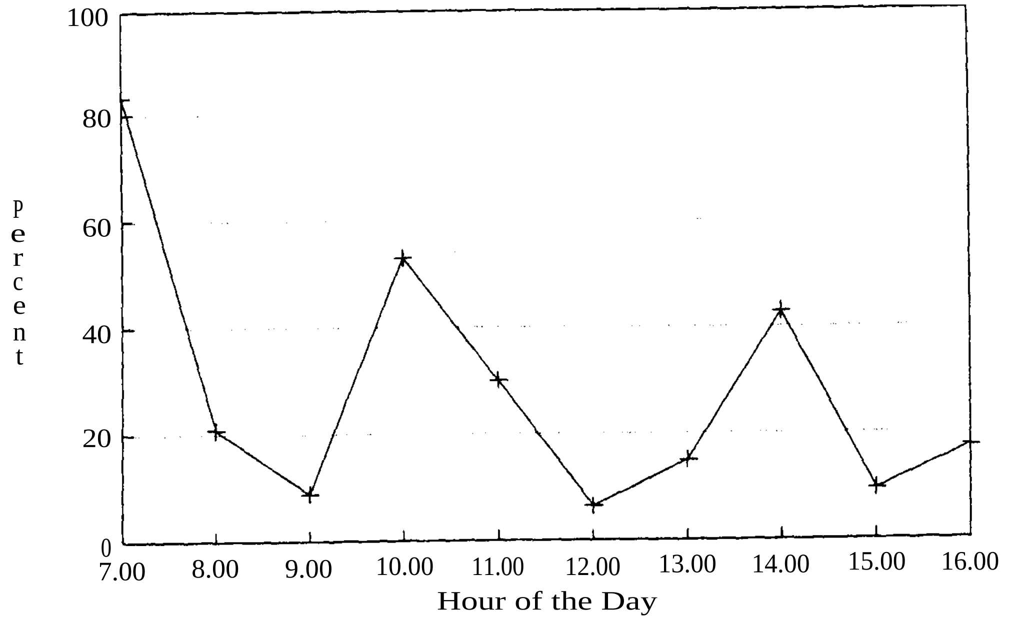


Figure 6 **Change in proportion of encounters in each hour of the day which had whale-watching vessels present**

This type of boat also has its drawbacks. They are noisy and have a high fuel consumption. They can carry a relatively small number of passengers, have few facilities and can be uncomfortable. This means that the trips are more suitable for the reasonably young and physically fit. It must also limit the amount of information which can be relayed to the tourists which would detract from the operation's role in public awareness and education.

In March 1992, Kaikoura Tours commissioned a larger 12.6 metre vessel of similar design powered by twin 250 hp. engines. It was not possible to observe this boat with whales during this study but measurements of its noise spectra at various speeds were made (see Appendix 1).

In summer, the tour boats made up to four trips per day, these were at dawn, mid morning, early afternoon and late afternoon. Figure 6 shows the proportion of encounters for which one or more boats were present throughout the day. The study vessel had usually started for home before the late afternoon trips and strong onshore winds frequently occurred in the afternoon resulting in fewer afternoon trips than morning ones.

Typically all four boats would leave South Bay at much the same time. They would spread out to a greater or lesser extent depending on conditions and the number and distribution of whales available. The boats generally headed southeast from the Kaikoura peninsula often following particular well-known transects. Once in a suitable area the boats would be stopped every few kilometres and directional hydrophones would be monitored to detect and obtain bearings to vocalising whales.

Directional hydrophones are a recent innovation to this operation, they have come into use in the last year, since MacGibbon's report. The design was developed locally by Kaikoura Tours and makes ingenious use of components which are cheap and readily available. The hydrophones are light and compact, and can be easily dipped over the side by the skipper when the boat stops. They seem not to be very sensitive by comparison to the hydrophones used on the study vessel (Chappell, pers. obs.) but were effective enough to be of great assistance.

Sperm whales dive for about 45 minutes, and because whale watching trips were relatively short, it was not usual for whale watching vessels to be with a whale for two consecutive encounters. There were occasions when whale watching boats visited the same individual whale on each trip through the day. In such cases an individual whale would actually be with boats on the surface for four surfacing periods of about 10 minutes each through the day. Assuming a dive cycle time (fluke to fluke) of 60 minutes (Section 3.2.4) then it would be joined by whale watching boats on 1/3 of all daylight surfacings and 1/6 of total surfacings (assuming diving behaviour continues at the same rate day and night).

The extent to which attention can be focused on a single individual is illustrated by considering data from "White Dot'; the most frequently encountered individual and the whale which received most attention from the whale watching boats.

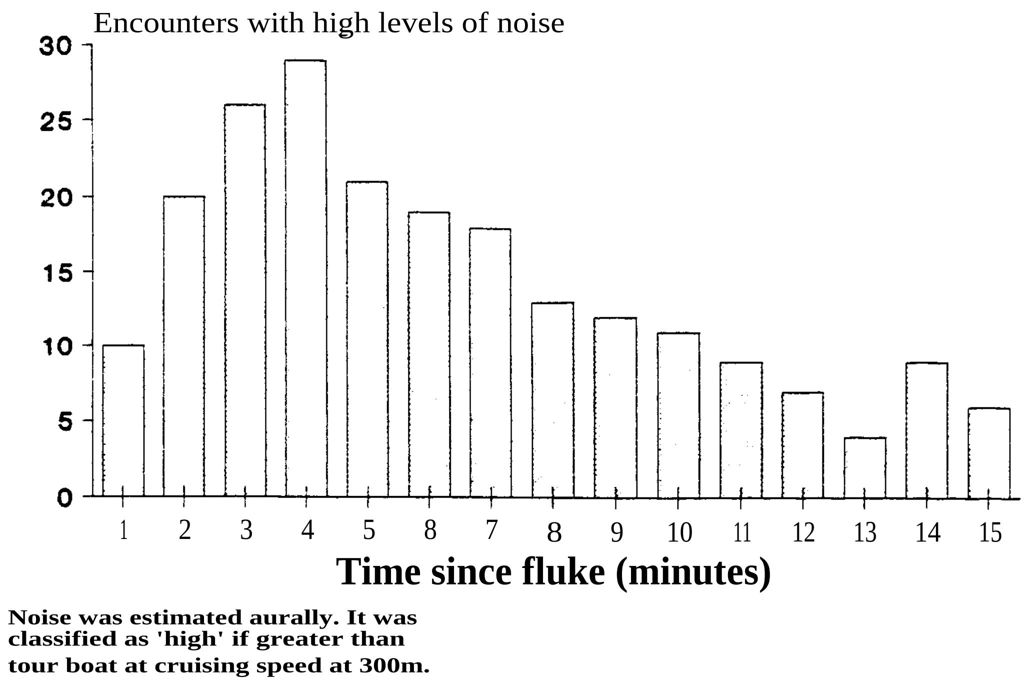


Figure 7 **Change in number of encounters, for which there was a high level of boat noise, with time after fluke up. Occasions when boats came over to study vessel to talk have been excluded.**

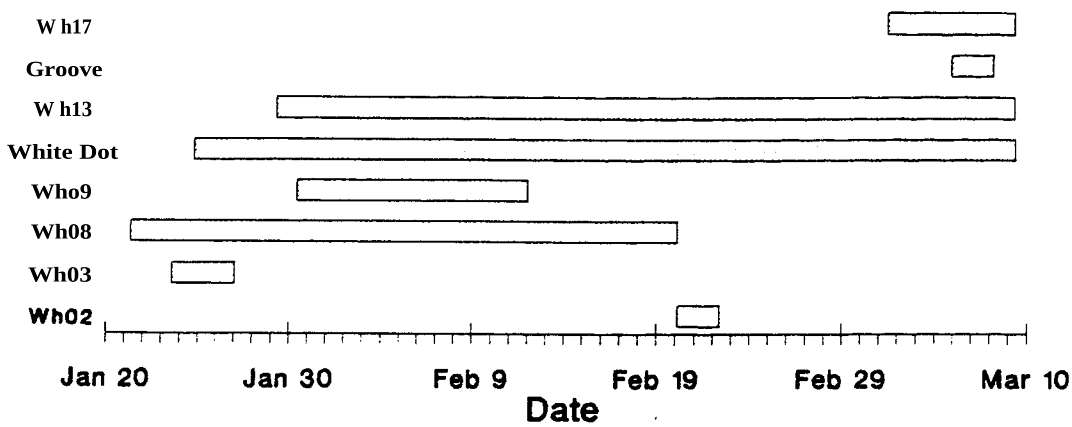


Figure 8 **Time between first and last sightings of identified whales.**

The study vessel had 63 encounters with "White Dot". Tour boats were present for 23 (36.5%) of these and boats were observed to be with "White Dot" on two sequential dives on four occasions. On 23rd of February 1992 "White Dot" was followed through a complete working day with 11 surfacings being observed between 0806 and 1643 (Figure 13 shows the positions of these encounters). Whale watching boats were present for 5 (45%) of these encounters.

MacGibbon (1991) reported that in the winter months, when one seemingly tolerant individual ("Hoop") could be predictably found close to shore, it was visited up to two or three times during a single whale-watching trip. Thus in the winter some whales may have boats present for an even greater proportion of their daylight surfacings.

On a few occasions insensitive boat handling of whale-watching boats working with whales was observed. Jane MacGibbon spent many days working on the study vessel and commented on the improvements in boat handling which were evident since 1990/91 when she collected the data for her study. Some of this can be attributed to the use of directional hydrophones which allow the boats to be well positioned close to whales when they return to the surface so that they have plenty of time to approach the whales steadily.

After the whales fluked up the boats moved away often waiting for several minutes before driving at full speed as indicated in Figure 7. The highest number of encounters with high levels of boat noise occurred 4 minutes after fluke up. Boat noise thereafter declined as the boats moved away from the research vessel and the whale.

3.2 Whale Behaviour

3.2.1 General description of whale surface behaviour. Over 98% of encounters in this study were with single whales. There were two encounters offshore with a groups of approximately 50 small sperm whales believed to be immature whales. Generally pairs and groups were very rarely seen. Only data from encounters with single animals were used for statistical analysis.

Most of the whales encountered during the study appeared to be feeding. They were making long dives with periods of recovery on the surface. A notable exception was a whale which was observed for over an hour and a half breathing slowly on the surface and sinking underwater between breaths. This whale appeared to be resting. It was making no noise and was not visually conspicuous and it is unlikely that whales behaving like this would often be found and possibly disturbed by whale watching vessels. Other whales which often dived without fluking, made short shallow dives and exhibited low blow rates may also have been resting. Data from these whales have been excluded from some of the analyses.

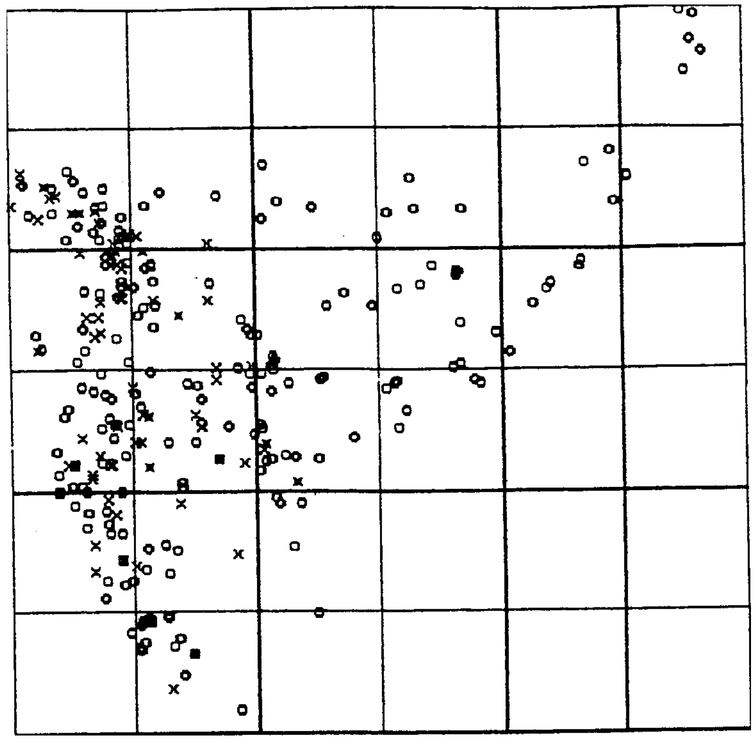


Figure 9 Positions of all encounters with whales with and without whale-watching vessels overlaid on 5 km grid. (See Figure 1 for reference)

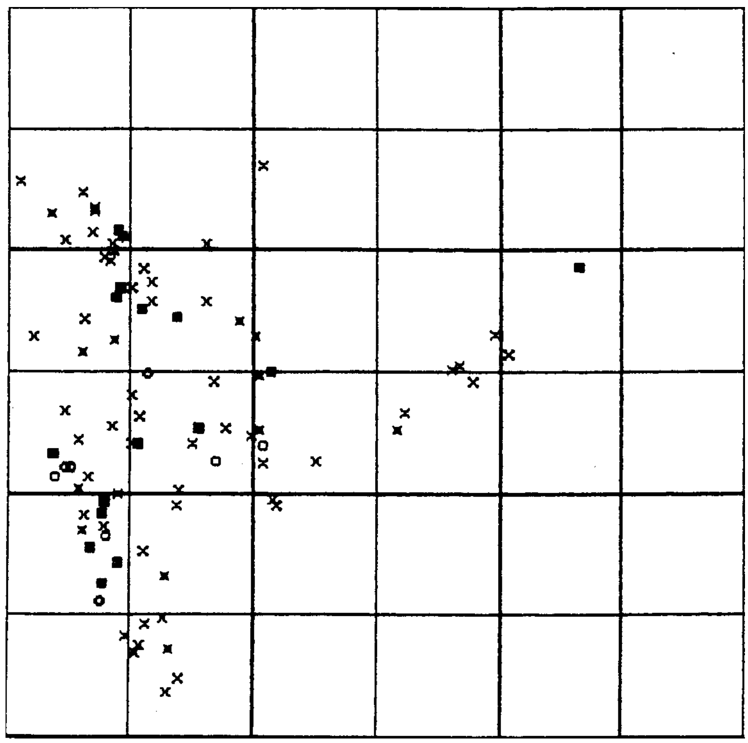


Figure 10 Positions of all encounters with whales when helicopters or planes were present, overlaid on 5 km grid. (See Figure 1 for reference)

3.2.2 Individual identification. Seventeen individual whales could be identified from marks on their flukes or other parts of their bodies. Identified individuals were given numbers but in cases where the individuals were well known to the whale-watch operators the names used by them (e.g. "White Dot" and "Groove") were adopted. Eight whales were sighted on at least two different days. For analytical purposes these individuals have been termed "identified whales". Encounters with "unidentified whales" were all encounters where it was not possible to recognise the individual as being an "identified whale". "Unidentified whale" encounters are thus likely to include some encounters with "identified whales" where recognition was not possible. Figure 8 indicates that identified individuals, in particular "White Dot" and whale 13, were in the study area throughout most of the study period.

3.2.3 Locations of encounters. Figure 9 shows the positions of all encounters overlaid on the 6x6 grid of 5 km squares (See also Figure 1). This plot is the result of searching effort directed in areas believed to be good for whales, rather than predetermined surveys and no attempts were made to correct for effort. Hence it gives only a very approximate indication of whale distribution.

There were few encounters in water less than 500 m deep, and those in shallower water were always close to very steep bottom gradients. No whales were encountered to the west of 173° 40'E. The study vessel made several passes through this area monitoring hydrophones and detected no whales. Tour boats, local fishing boats and aircraft often passed through this area but no sightings of sperm whale were reported to the team. This agrees with observations that whales only use this inshore region during the winter (MacGibbon, 1991; Oliver pers. Comm.).

A large number of encounters took place along the 1000 metre contour which runs roughly north south up the coast and in towards the shore south of the Kaikoura peninsula. It was also in this region that the majority of the encounters with tour boats present took place (Figure 9). This reflects the transects along which the tour boat operators generally searched as well as any effects of whale abundance. Whales were also found well outside this area, even though very little effort was expended in this offshore region. The distribution of encounters for which planes and helicopters were present (Figure 10) indicates that they had more encounters with whales further offshore than the boats did.

Encounters with identified individuals are shown in Figure 11. They were found in a fairly restricted area similar to that used by the tour boats. "White Dot" in particular had a discrete range centred around the mouth of the deep gully which runs in towards the shore to the south of Kaikoura.

3.2.4 Dive cycle. Mean fluke to fluke, surface and dive times for different whales encountered in this study are presented in Table 1. The relatively long mean surface time for whale 13 is due to the inclusion of a very long period at the surface, possibly resting, described above.

Table 1. Summary of Dive Cycle Parameters

	No. of Encounters n	Surface Time minutes	Change in Heading degrees	No. of observed dive cycles	Est. dive time minutes	Fluke to Fluke time minutes	Travel rate knots
Unident. whales	155	10.0 6.7	18.4 34.3	*	*	*	*
White Dot	63	8.1 2.1	21.5 29.9	36	44.8 7.3	52.7 8.15	1.08 0.48
Wh 13	15	17.0 22.4	31.3 37.6	10	51.7 4.6	63.8 5.54	1.29 0.52
Groove	7	10.2 1.8	24.3 33.1	4	52.1 3.1	61.7 2.15	0.79 0.45
Wh 9	7	7.9 5.1	15.7 33.1	3	34.5 6.3	39.6 3.94	1.27 0.87
Wh 8	5	9.0 1.8	21.0 18.8	0	*	*	*

Upper figure is mean value
Lower figure is standard deviation
* indicates that no data were available

Table 2. Summary of Blow Interval Data for Different Whales.

Whale ID	No. of obs.	Mean of mean blow interval (s)	Median of mean Blow interval (s)	Mode of mean blow intervals (s)	Mean of Standard Deviation	Mean of Number of Blows
Unident.	155	17.61	16.00	16.00	6.52	31.43
White Dot	62	15.13	14.00	14.00	4.00	32.53
Wh 13	15	18.13	15.00	15.00	13.14	45.07
Wh 9	7	14.69	13.00	13.00	2.04	31.43
Wh 8	5	14.18	13.00	13.00	1.29	37.60

Data summarised are for encounters which ended with fluking.

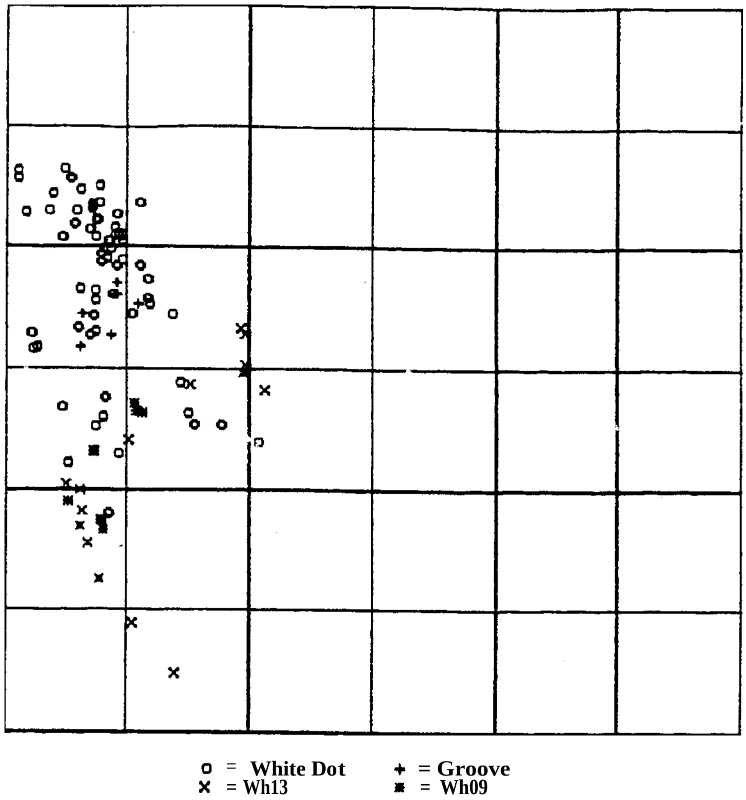


Figure 11 Positions of all encounters with identified whales overlaid on 5 km grid. (See Figure 1 for reference)

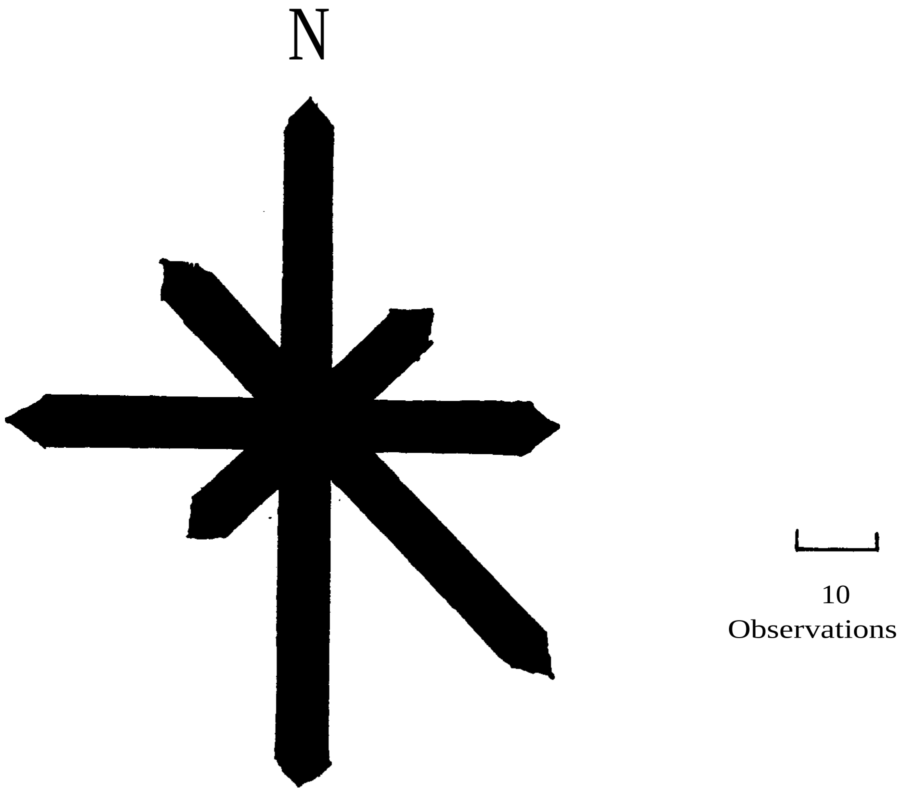


Figure 12 Distribution of whale headings (true) from all encounters with single individuals (n=272).

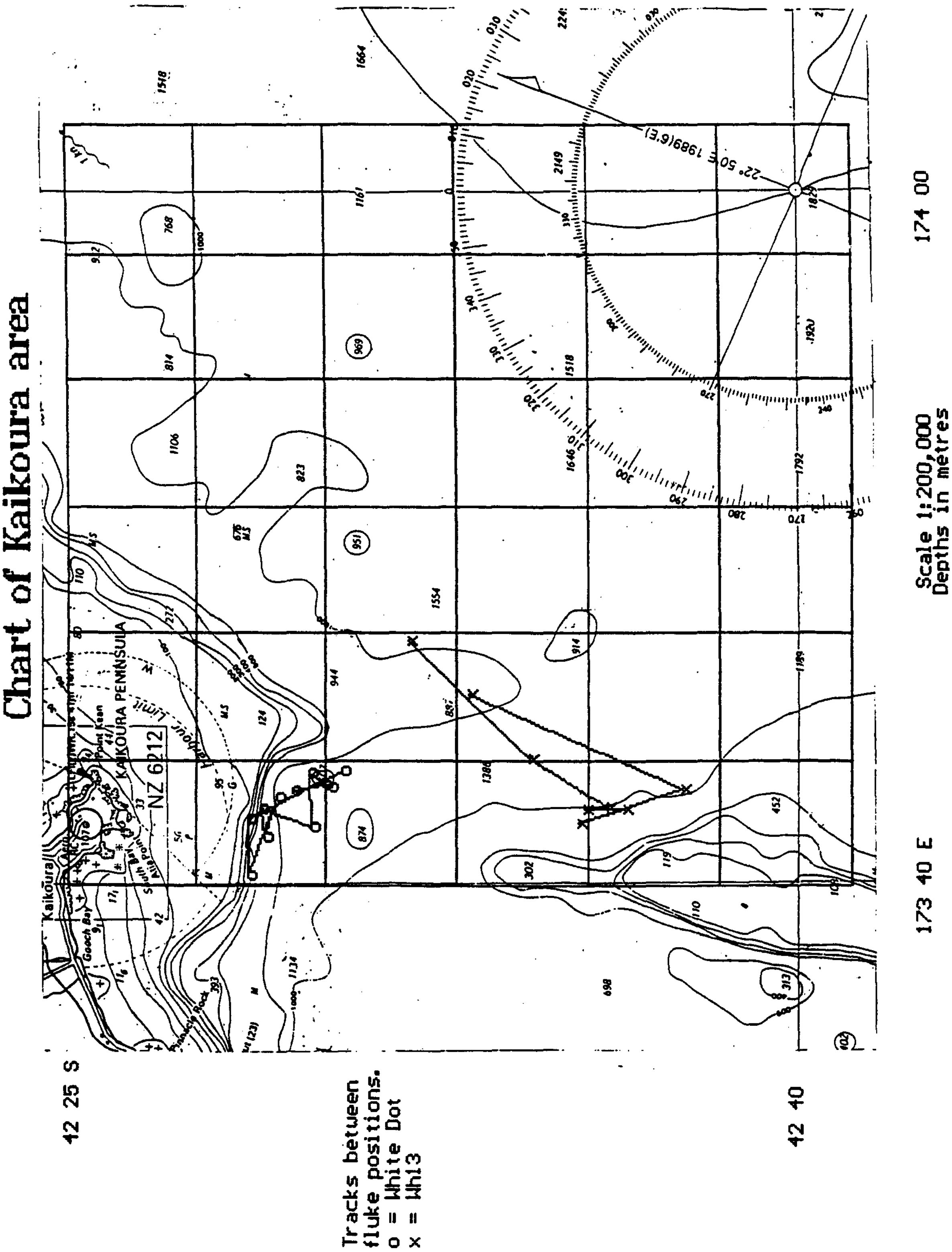


Figure 13 **Positions for sequences of encounters on single days for two identified whales**

Table 3. Results of Statistical Tests on Visual Parameters

Series 1
DATA SELECTED FOR ANALYSIS: All data. (n=2x32)
INDEPENDENT VARIABLE. Presence or absence of tour boats within 450m.
TEST: Mann Whitney U test

Mean Interval.	.084	Surface Time	.007 **
SD/Mean	.485	Fluke to Fluke(n=55)	.830
Number of Blows	.010 **	ESL Dive Length(n=55)	.468

Series 2
DATA SELECTED FOR ANALYSIS: No Boats Present (n=176)
INDEPENDENT VARIABLE: Identity of whale
TEST. Kruskal-Wallis Test

Mean Interval.	.000 ***	Surface Time	.078
SD/Mean	.086	Fluke to Fluke(n=37)	.001 ***
Number of Blows	.015 *	Est Dive Length (n=37)	.003 **

Series 2.1
DATA SELECTED FOR ANALYSIS: Encounters with unidentified whales and "White Dot" with No Boats Present (n=147)
INDEPENDENT VARIABLE: Identity of whale
TEST: Mann-Whitney U Test

Mean Interval-	.000 ***	Surface Time	.234
SD/Mean	.004 **	Fluke to Fluke(n=25)	.127
Number of Blows	.614	Est. Dive Length(n=25)	.166

Series 2.2
DATA SELECTED FOR ANALYSIS: Encounters with identified whales with no Boats Present (n=68)
INDEPENDENT VARIABLE. Identity of whale
TEST: Kruskal-Wallis Test

Mean Interval-	.235	Surface Time	.006 **
SD/Mean	.710	Fluke to Fluke(n=36)	.005 **
Number of Blows	.009 **	ESL Dive Length(n=36)	.002 **

Series 23
DATA SELECTED FOR ANALYSIS: Encounters with all identified whales excluding white dot and with no Boats Present (n=29)
INDEPENDENT VARIABLE: Identity of whale
TEST: Kruskal-Wallis Test

Mean Interval.	.208	Surface Tune	216
SD/Mean	.554	Fluke to Fluke(n=12)	.192
Number of Blows	.285	Est. Dive Length(n=12)	.225

Series 2.4
DATA SELECTED FOR ANALYSIS: Data from Shelf Zone with no boats present (n=176)
INDEPENDENT VARIABLE: Identity of whale
TEST. Kruskal-Wallis Test

Mean Interval.	.010 **	Surface Tune	.057
SD/Mean	210	Fluke to Fluke(n=36)	.001 ***
Number of Blows	.023 *	Est. Dive Length(n=36)	.002 **

Series 3
DATA SELECTED FOR ANALYSIS: Unidentified Whales (n=138)
INDEPENDENT VARIABLE- Presence or absence of boats within 450m.
TEST. Mann-Whitney U Test

Mean Interval.	.025 *	Surface Time	.035 *
SD/Mean	.767	Fluke to Fluke (Insufficient Data)	
Number of Blows	.074	Est. Dive Length (Insufficient Data)	

Series 4
DATA SELECTED FOR ANALYSIS: Encounter with "white Dot" (n=62)
INDEPENDENT VARIABLE: Presence or absence of boats within 450m.
TEST: Mann Whitney U Test

Mean Interval.	.402	Surface Time	.218
SD/Mean	.741	Fluke to Fluke(n=36)	.115
Number of Blows	.201	Est Dive Length(a=36)	.042 *

Series 5
DATA SELECTED FOR ANALYSIS- Encounters with "whale 13" (n=15)
INDEPENDENT VARIABLE: Presence or absence of boats within 450m.
TEST. Mann-Whitney U Test

Mesa Interval.	.083	Surface Time	.112
SD/Mean	.060	Fluke to Fluke(n=10)	.601
Number of Blows	.942	Est Dive Length(n=10)	.296

Series 6
DATA SELECTED FOR ANALYSIS: Encounters with unidentified whales with no tour boats within 450m (n=131)
INDEPENDENT VARIABLE: Encounter position in offshore or shelf zone.
TEST- Mann-Whitney U Test

Mean Interval.	.070	Surface Time	.982
SD/Mean	.640	Fluke to Fluke (Insufficient Data)	
Number of Blows	.406	Est Dive Length (Insufficient Data)	

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 a fluke-up have been analyzed.

Fluke to fluke and dive times could only be measured when whales were positively identified at either end of a dive, hence there are fewer data for these parameters.

Table 4. Summary of surface data and dive cycle parameters for encounters with and without boats.

	n	Mean blow interval (sec)	Standard Deviation Blow Int.	Number of Blows	Surface Time (min)	Fluke to Fluke (min)	Estimated Dive time (min)
No Boats	177	16.75 3.34	6.52 4.23	34.34 12.45	9.46 3.95	54.98 9.35	45.59 7.36
Boats	65	17.18 7.19	9.05 20.01	30.24 11.77	7.82 3.56	55.40 9.8	47.48 8.24

Data summarised are for encounters which ended with fluking.
Standard deviations are standard deviations of blow intervals for each encounter.

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=.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 (Ohlsohn, 1991).

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.

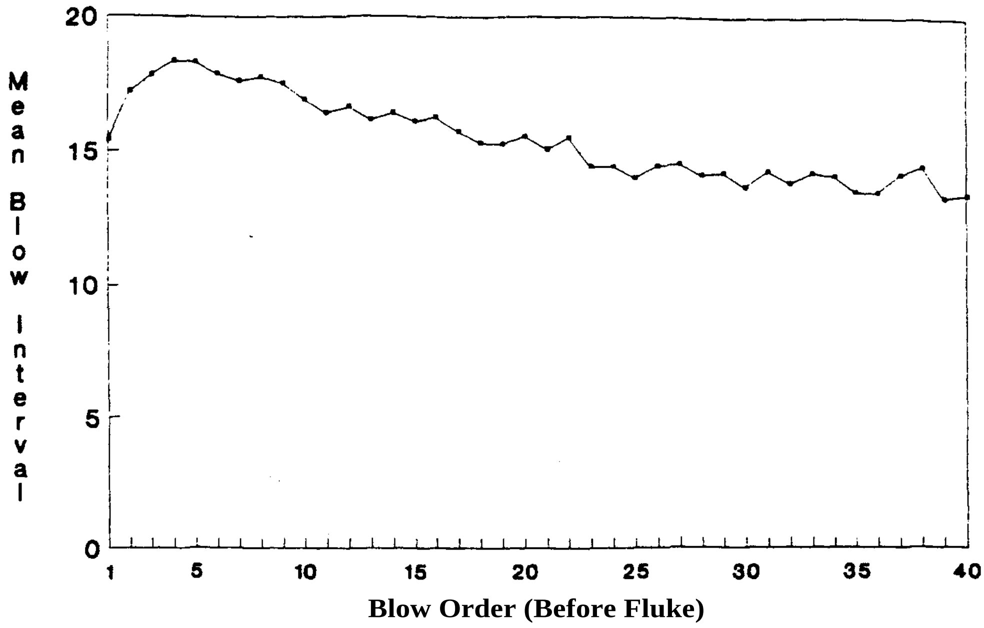


Figure 14 Mean values of blow intervals (seconds) through surfacing. Blow order is with reference to fluke up. First interval before fluke up is one, interval before that is 2 etc. Time travels from right to left. Mean blow interval 1 is mean for all encounters of all first blow intervals before fluke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

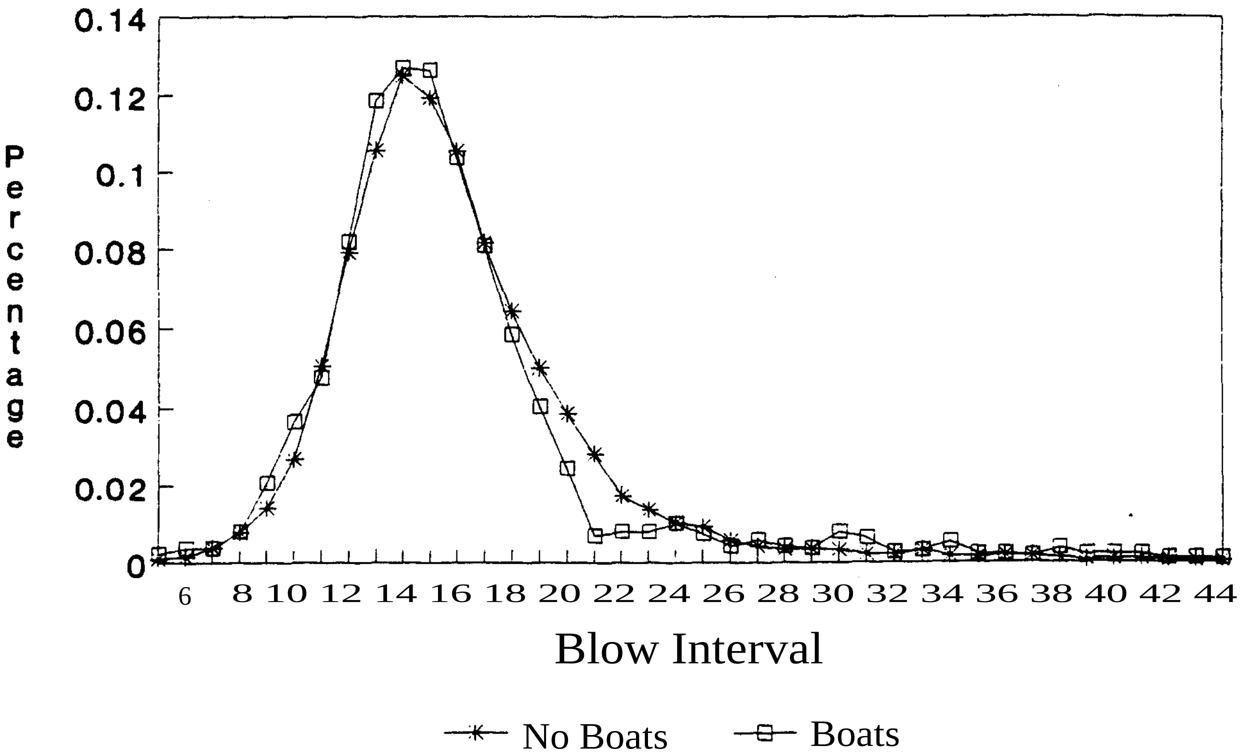


Figure 15 Distributions of all blow intervals (seconds) logged from encounters with and without whale-watching boats present

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 8 4% 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's shorter 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

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