Sperm whale watching off Kaikoura, New Zealand: effects of current activities on surfacing and vocalisation patterns

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CONTENTS

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ABSTRACT

Off Kaikoura, South Island, New Zealand, sperm whales (*Physeter macrocephalus*) are the focus of a whale watching industry which uses boats and aircraft to view the animals year-round. This study employed boat-based and shore-based observations to determine the impacts of current whale watching activities on the whales. Over four years (1998–2001), we recorded 1676 sightings from the research vessel and 435 from shore. Several aspects of whale behaviour were significantly affected by the presence of whale watching vessels. Blow interval (mean and median) decreased in the presence of the research vessel and/or whale watching boats. Whale watching boats and aircraft, individually or together, caused increases in the time whales spent at the surface and in the frequency and amount of heading changes. Boats caused a decrease in the time to the first click. Aerial behaviours were more frequent when only the research vessel was present. Two groups of sperm whales are distinguishable off Kaikoura: resident whales, which typically stay in the study area for weeks or months at a time, often returning in different seasons and/or years; and transients, which are seen on one day only. Transients reacted more frequently and more strongly to boats. However, they are rarely visited by whale watching trips because of their further offshore distribution. Residents reacted less and received most of the whale watching activity. Our study showed that whale reactions to whale watching boats varied significantly among different individuals. Some whales were very tolerant. Whale reactions also varied with season. Our survey indicates that effects of whale watching on resident whales, while statistically detectable, appear to be sustainable, and of no serious biological consequence. However, current whale watching effort on residents is high, and some individual whales may spend approximately half of their surfacings during the busy summer season accompanied by one or more boats. Given management options of reducing, maintaining or increasing the level of permitted whale watching activities, we recommend that the current level be maintained.

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1. Introduction

1.1 THE DEVELOPMENT OF WHALE WATCHING

Commercial whale watching has spread worldwide since its beginning in 1955 (Hoyt 2001). The first commercial enterprises were located in California, where gray whales (*Eschrichtius robustus*) migrate close to shore. Less than 30 years later commercial whale watching began in Europe (Hoyt 1996). Since then, progress has been rapid. In 1994, 65 countries had whale watching businesses. Four years later, this number had climbed to 87 (Hoyt 2001). While the initial focus was on gray and humpback whales (*Megaptera novaeangliae*), most cetacean species are now occasionally subject to whale watching.

Whale watching has experienced a comparable economic growth. From earning US$14 million in 1981, it grew to over US$300 million ten years later. Latest estimates exceed the US$1,000 million mark for 1998 (Hoyt 2001).

As a result, high hopes are commonly associated with the whale watching industry. Many remote locations with little economic opportunity have become major tourist attractions and are now significant employers. Economic benefits also flow to associated businesses. Benefits from this economic and social development can be numerous and important.

Kaikoura is probably one of the better known examples of such a development. Early settlers came to the area to utilise its natural resources: Maori hunted moa and fished (McAloon et al. 1998); Europeans came in order to whale, setting up whaling stations as early as the 1830s. Whaling continued until 1920 in South Bay, although only on a small scale. Farming became the dominant employer after the establishment of the first farm in 1847, and remained the most important source of income until construction of the railway commenced in the 1940s. Consequently, the transport industry as well as the services sector were the most important employers during most of the 20th century. During this period, the community was rather opposed to the development of tourism in the area. This attitude changed only in the 1980s with the loss of numerous jobs due to restructuring of the railway and government sectors (Horn et al. 1998; McAloon et al. 1998). The local Maori community was likely most affected by these processes (Horn et al. 1998).

Individuals from the Maori community were among the first to consider starting up whale watching off Kaikoura (Poharama et al. 1998). Whale watching began in 1988 and is now being carried out by one boat-based and two aircraft-based companies. Even though direct measures of increased employment in tourism are not available, it is obvious that tourism along with other service industry sectors showed strong increases, in contrast to fishing and government employment (Butcher et al. 1998). For example, employment in recreation services increased by 400% between 1986 and 1999. In 1996, approximately 25% of all jobs in Kaikoura were directly related to tourism. In turn, each of these tourism jobs created a further 0.21 jobs in other sectors (Butcher et al. 1998).

Positive effects from whale watching can go beyond local economies. Educational opportunities are often cited as a further important aspect (Beach & Weinrich 1989; Forestell 1993). The often new and unusual conditions of a whale watching trip can be a powerful and effective setting to transmit information and messages relating to, for example, conservation issues in general and protection of marine habitat in particular (Forestell 1993). In addition, many NGOs have argued that whale watching is a viable alternative to whaling (e.g. Greenpeace, undated) and can thus have impacts on national as well as international politics and conservation efforts (Ris 1993). Very little research has been carried out to quantify these aspects of whale watching industries. Similarly, little information is available on potential negative influences. For example, communities have to adapt to increasing visitor numbers, thus altering economic, social and cultural patterns (IFAW 1999).

While these kinds of changes may not initially be perceived as negative, once they pass a certain threshold or it becomes obvious that the continuing development of the industry necessitates significant change, some members of the community may find these new or constantly changing conditions unacceptable. Once again, Kaikoura provides an example. In a survey carried out in 1997 and 1998, just under half of the respondents stated that the tourism development in Kaikoura had brought negative rather than positive consequences. These included overcrowding, lack of infrastructure, increased costs of living, and lifestyle changes. It was also argued that only certain and limited groups of the society benefited from recent developments, thus causing social inequality (Horn et al. 1998). Similarly, in a study of the local gray whale watching industry in two communities on the Baja California peninsula, Mexico, Young (1999) found that only a small proportion of the revenues actually remained in the communities. In addition, conflicts over access to marine resources had become more frequent with the growth of whale watching.

Socially, it is important that the community accepts and supports the development occurring with whale watching. However, in order for whale watching to be sustainable, the biological impact of the activities must be minimal. If, for example, the whales leave the area or become boat-negative in response to whale watching activities, whale watching will have undermined its own future. Knight & Cole (1995) list four ways in which recreationalists can impact wildlife in general: exploitation, pollution, disturbance and habitat modification. While killing whales and dolphins is not part of commercial whale watching, and additional pollution due to whale watching vessels is likely to be negligible compared with pollution from general shipping and land run-off (Harwood 2001), whale watching activities can disturb whales and modify their habitat.

Of greatest general concern is the impact of increasing noise levels on whales. All whales and dolphins rely on sound (Richardson et al. 1995). For example, Odontocetes (including sperm whales) find their prey by echolocation, and baleen whales may use sound for long-range navigation or communication. Consequently, any changes in the acoustic environment may affect these functions. Communication sounds may be masked by increased noise levels, animals may leave noisy locations, fall silent or change behaviour patterns in response to noise exposure (Richardson et al. 1995; Erbe & Farmer 2000).

The general literature on impacts of sound on marine mammals is extensive and indicates that reactions to sound can range from attraction to the sound's source, to avoidance of it. Avoidance can happen at ranges of tens of kilometres from the source, and whales may completely abandon ensonified areas (Richardson et al. 1995). However, results from these studies are difficult or impossible to transfer to whale watching impacts due to differences in sound sources, methods and biological contexts. Therefore, more specialised research on effects of whale watching activities on whales is urgently needed (Hofman 1995; IFAW et al. 1995).

1.2 WHALE WATCHING IMPACTS

Whales have been observed to respond to whale watching activities in a variety of ways. A significant problem is that the habitat makes observing whale behaviour very difficult. Underwater behaviour is largely inaccessible to researchers. The most easily observed reactions are whether whales approach or attempt to avoid approaching vessels. In an analysis of 25 years of observations collected off Cape Cod, Watkins (1986) found that humpback whales increasingly approached vessels, while fin whales (*Balaenoptera physalus*) had stopped approaching whale watching vessels and seemed to ignore them. However, avoidance and attraction are not necessarily exclusive. Studies have shown that Hector's dolphins (*Cephalorhynchus hectori*) typically approach an incoming vessel. As the interaction continues, however, the dolphins approach less frequently and show more neutral and avoidance movements (Bejder et al. 1999).

Ventilation patterns and swimming behaviour of whales in response to vessels can also be observed easily. When vessels are present, many baleen whales alter intervals between blows and the time spent at the surface between long dives. For example, humpback whales reduced blow intervals when vessels approached (Baker & Herman 1989). While blow intervals of fin whales did not change in the presence of boats, these whales reduced dive duration, time at the surface and the number of blows per surfacing (Stone et al. 1992). Comparable changes were observed in gray whales (Bass 2000). In contrast, breathing patterns of southern right whales (*Eubalaena australis*) did not change significantly when they were approached by boats (Findlay 1999). Killer whales (*Orcinus orca*) and humpback whales altered swimming speed when vessels appeared (Baker & Herman 1989; Kruse 1991). Also, whales occasionally altered travel orientation when vessels approached (Richardson et al. 1995).

Individual behaviours, or relationships among behaviours or group dispersion can change in the presence of boats. For example, dusky dolphins (*Lagenorhynchus obscurus*) may jump more often in the presence of boats (Barr & Slooten 1999). Humpback whales, on their migration path past eastern Australia, changed their patterns of behaviour such that breaching occurred more often in association with peduncle flipper slaps in the presence of vessels (Corkeron 1995). Furthermore, dusky and Hector's dolphins have responded to tourist boats by forming tighter groups (Barr & Slooten 1999; Bejder et al. 1999).

In extreme cases, groups of animals may leave an area completely or reduce the time spent there. For example, gray whales left Guerrero Negro Lagoon, Mexico because of heavy boat traffic; they returned once traffic subsided (Jones & Swartz 1984). Hawaiian spinner dolphins (*Stenella longirostris*) have reduced the time they spend resting in certain bays since increasing numbers of vessels visited them in these areas (Driscoll-Lind & Östman-Lind 1999).

Changes in vocal behaviour have also been described for several whale and dolphin species. Beluga whales (*Delphinapterus leucas*), target of whale watching in the St. Lawrence River, Canada, responded to vessels by reduced calling rates, increased use and repetition of certain calls, and shifts to higher frequencies (Lesage et al. 1999). Humpbacks shortened their songs when vessels approached (Norris 1994) and bottlenose dolphins (*Tursiops truncatus*) whistled more in the presence of whale watching vessels (Scarpaci et al. 2000). Similarly, Pacific humpback dolphins (*Sousa chinensis*) increased whistle frequency after boats had passed. These changes depended on whether calves were present in the groups (van Parijs & Corkeron 2001).

Research on the influence of recreationists on the behaviour of land mammals has shown that, under certain circumstances, most targeted species habituate to human presence and activity (Knight & Cole 1995). Even though comparable literature on marine mammals is sparse, some studies have shown that whales and dolphins also habituate to whale watching. Over 25 years of whale watching at Cape Cod, minke whales (*Balaenoptera acutorostrata*) and fin whales learned to ignore whale watching vessels (Watkins 1986). Similarly, both gray and beluga whales have shown lessening responses with time to whale watching boats (Jones & Swartz 1984; Blane 1990).

It is also possible that whales remain in an area and/or continue with normal behaviour, such as feeding, despite the presence of whale watching vessels. Such apparent tolerance does not imply lack of impact. Indeed, by definition, tolerance implies that a biologically significant disturbance is endured due to the importance of the particular activity or location to the animals (IFAW et al. 1995). Without knowledge of the importance of the area and/or the activity relative to available alternatives, lack of response to a disturbance is difficult to interpret.

As the above examples illustrate, results are often inconsistent among studies. There are a variety of possible reasons for this. First, that species should react differently is not surprising because of their differences in behaviour and ecology. For example, while belugas reacted to ice-breaking ships by swimming faster, calling more, and spreading out, narwhals (*Monodon monoceros*) responded by 'freezing', which is characterised by slow or no movement, cessation of vocalisations and close body contact (Finley et al. 1990).

Second, individual experiences influence the way cetaceans respond to anthropogenic disturbances. For instance, belugas in areas where they were hunted responded differently from individuals in regions where no hunt occurred (Richardson et al. 1995). Age of the animals also made a difference, with young belugas responding less than adults (Blane 1990). Beaufort Sea bowheads avoided motorised boats more than unmotorised boats. Considering that they were hunted from boats with motors, this sensitivity to them is unsurprising (and adaptive) (Richardson et al. 1995).

A third factor is the animals' activity, or motivational state when the disturbance occurs. Feeding or travelling belugas were less likely to respond to vessels, compared with belugas involved in other behaviours (Blane 1990; Blane & Jaakson 1994). Similar differences are described for humpback, fin and blue whales (*Balaenoptera musculus*) (Richardson et al. 1995). In addition, there is evidence that reaction of humpbacks to vessels also depends on pod composition (Corkeron 1995). It is almost inevitable that individuals within a population will react differently, as some will be more risk-averse than others.

Lastly, a vessel's size and behaviour strongly influences whether and how cetaceans react to it. Slow approaches and smaller vessels caused fewer belugas to respond than fast approaches and large vessels (Blane 1990; Lesage et al. 1999). Similarly, while minke whales generally avoided moving vessels they have occasionally approached stationary boats, or those moving slowly (Richardson et al. 1995). Reactions to boats can also depend on the length of an encounter: Hector's dolphins display more neutral and avoidance movements after encounters with vessels have lasted for approximately 70 minutes (Bejder et al. 1999).

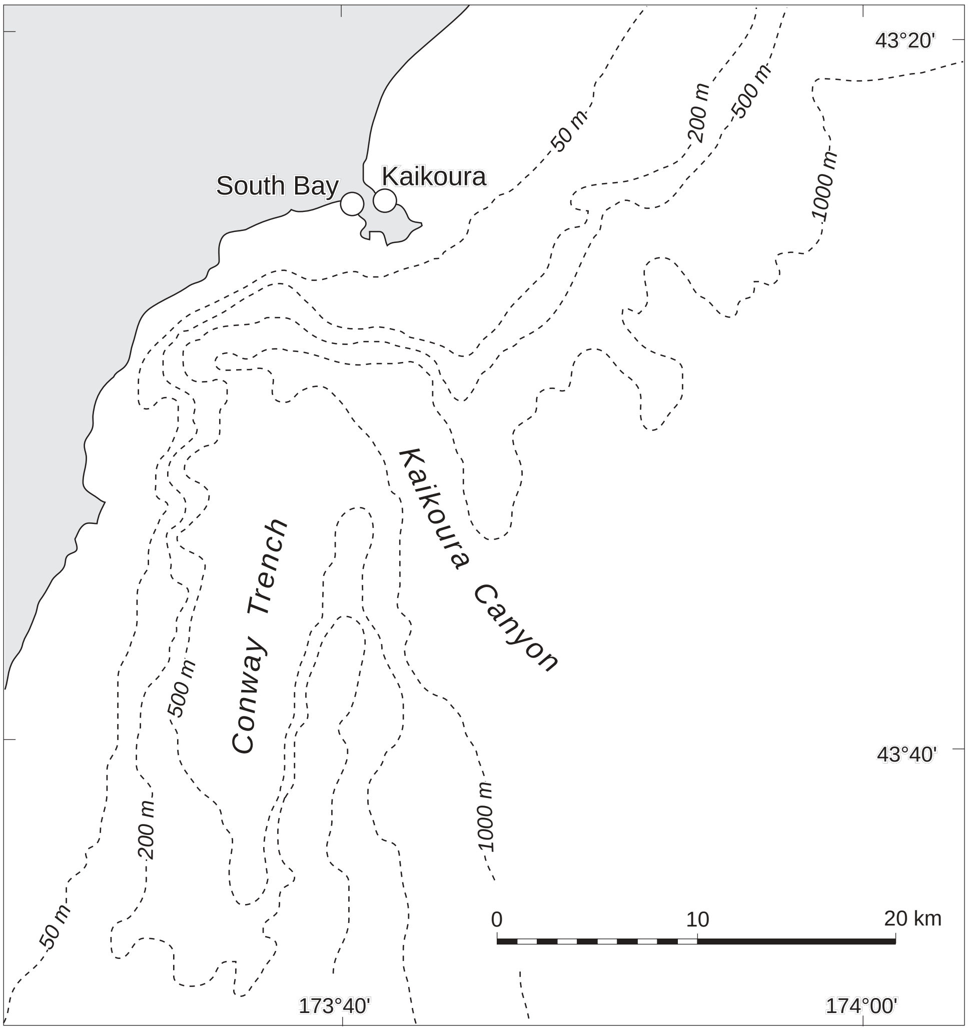
In summary, numerous factors such as species, motivation, current behaviour, age, boat type and activity have been shown to influence responses of cetaceans to vessels. In most cases, animals engaged in feeding, travelling or socialising react less than when involved in other activities. Fast and erratically moving boats appear to be more disturbing than vessels approaching whales slowly and with few directional changes. It is therefore important to consider the above-mentioned factors and conditions in the analysis of our data and interpretation of the results of this report.

1.3 KAIKOURA SPERM WHALES

Sperm whales are remarkable in several respects. First, they are the most sexually dimorphic of all cetaceans: females grow to approximately 12 m and 24 metric tons, while males of up to 18 m and 60 metric tons have been recorded. Second, with killer whales they share the widest distribution of all marine mammals, being present in all oceans and across all latitudes (Rice 1989). However, this global distribution is divided by sex. Females and their offspring rarely leave tropical or sub-tropical waters. Males, once they attain sexual maturity (around 6 years), leave these mixed groups and form pods with other males of similar age. With increasing age, male sperm whales become increasingly solitary and expand their movements further towards the poles (Rice 1989).

Consequently, sperm whales off Kaikoura are almost exclusively males. Female groups have been observed by us only twice in 10 years of study (pers. obs). Whale distribution at Kaikoura is strongly related to the bathymetry of the Kaikoura canyon (Fig. 1), particularly in summer, when almost all sightings are made in waters deeper than 1000 m. This distribution is more diffuse in winter, when more whales are sighted over the Conway Trench (Jaquet et al. 2000) and in areas between 500 and 1000 m deep. This may be due to changes in prey composition and/or distribution.

Figure 1. Map of Kaikoura area, showing bathymetry and place names used in this report.



Apart from very occasional absences of a few days, sperm whales are present off Kaikoura year-round (Jaquet et al. 2000). The average residency time of individuals is 42 days (S.E. = 10.3; Lettevall et al. 2002). However, there is evidence for two groups with completely different residency patterns: transient individuals are seen only once, while resident animals remain off Kaikoura for several days or weeks and often return in more than two seasons (Jaquet et al. 2000). Generally, resident animals are sighted closer to shore than transient individuals (Childerhouse et al. 1995).

The behaviour of sperm whales off Kaikoura is predictable and changes only slightly with the season. Social behaviours are rarely seen, and almost all whales at the surface are alone. In summer, whales spend on average 9.3 min at the surface and their dives last 43.9 min. These values are reduced in winter with an average surface time of 8.8 min and dives lasting only 38.7 min (Jaquet et al. 2000). Throughout the year, diving patterns are consistent with foraging behaviour as defined by Whitehead & Weilgart (1991).

1.4 CURRENT WHALE WATCHING ACTIVITIES OFF KAIKOURA

1.4.1 Whale Watch Kaikoura Ltd

The only boat-based company in Kaikoura with permits to see dolphins as well as whales is Whale Watch™ Kaikoura Ltd. The iwi-based company was set up in 1987, took over a second permit from a another whale watching company in 1989 (Poharama et al. 1998) and has received national and international tourism awards. It is currently permitted to operate four vessels at any one time, with up to four trips per day, totalling a maximum of 16 trips per day (A. Baxter, DOC, pers. comm.). During the period of this study, it used five different vessels, only the oldest of which still employs outboard motors. This boat is a 12.6 m aluminium pontoon vessel powered by three 225 hp outboards and capable of carrying 32 passengers. The other vessels are all catamarans with inboard diesels powering jet drives. The smallest of these is 12.6 m long and its sister vessel measures 14.6 m. Both are equipped with twin 500 hp diesel engines. The two newest vessels are identical foil-assisted catamarans, 18 m long and powered by twin diesels with approximately 700 hp each. These vessels have space for up to 48 passengers each. The company offers six tours per day throughout the year with additional trips during the summer months. Tourists are shown a safety and introductory video before they enter the bus to drive to South Bay. From there, the vessels leave for trips lasting between two-and-a-half and three hours. Each trip is accompanied by three or four guides who have received in-house training and who share the duties of tour narrator, safety officer and watch officer. Refunds are given when no whales are seen, at the discretion of the skipper (www.whalewatch.co.nz).

1.4.2 Wings over Whales

Wings over Whales, stationed at the Kaikoura air field just south of the town, carries out whale watching flights using fixed-wing aircraft. Four-seater (Cessna 172 or Piper Cherokee) and nine-seater planes (Pilatus Britten Norman Islander) are used for the flights which typically last 30 minutes. Flights are scheduled by demand. Before the flight, tourists are introduced to plane safety procedures as well as the whales and dolphins of the area. During the flight, the pilots also act as tour guides. After the flight, every passenger receives a brochure with information about the company, Kaikoura and the whales. If no whales are spotted, a free second flight at the convenience of the passengers is offered (www.whales.co.nz).

1.4.3 Kaikoura Helicopters

The only company using helicopters (Bell Model 206 JetRanger) for marine mammal viewing in New Zealand began operations in 1991. Tours with up to four passengers are scheduled by demand and vary in length between 30 and 50 minutes. Before the flight, passengers are briefed on safety and on conditions out on the water. This includes an assessment of the likelihood of seeing sperm whales, based on the results of earlier flights, and from boat and plane trips (www.worldofwhales.co.nz).

1.5 OBJECTIVES OF THE CURRENT STUDY

The impacts of whale watching activities on Kaikoura sperm whales have been the subject of two previous studies. Between 1990 and 1991, MacGibbon (1991) investigated how distribution and breathing patterns of sperm whales changed in response to vessel presence. A more comprehensive study followed in 1992 where Gordon and colleagues (1992) recorded data on spatial and ventilation patterns and an array of acoustic characteristics. Operator conduct and equipment have improved in response to both studies. For example, directional hydrophones are now commonly used by whale watch operators to track whales, as suggested by MacGibbon (1991). Also, after Gordon et al. (1992) found that a local waterjet-powered boat was much quieter under water than any of the similar propeller-driven vessels, Whale Watch Kaikoura has switched to waterjets in all its boats built since. Therefore, significant changes in the way whale watching is being carried out have occurred since these studies. Meanwhile, the Otago Marine Mammal Research Group's more than decade-long research programme on the behaviour and ecology of the Kaikoura sperm whales (started in 1990) has contributed important details to our knowledge. Pressure on the Department of Conservation (DOC) for more whale watching permits, along with changes in the whale watching vessels, and their behaviour, warranted a new investigation into the responses of sperm whales to current whale watching activities.

The objectives of the present study were to:

- assess impacts of current activities on the behaviour and vocalisation of sperm whales
- determine if resident and transient sperm whales respond differently to whale watching vessels
- recommend optimum number and distribution of whale watching trips
- assess the carrying capacity for whale watching at Kaikoura
- provide recommendations on how to reduce impacts, and suggest amendments to the Marine Mammals Protection Act 1978, if required.

2. Methods

2.1 BOAT-BASED OBSERVATIONS

2.1.1 Equipment

Observations were carried out from *Cetos*, a 6.6 m rigid-hulled inflatable powered by a 90 hp outboard motor. Three to four people were typically on board. Positional information was obtained via GPS (KODAN KPG-900 or Garmin GPS126) which were connected to a Hewlett Packard 95LX palmtop computer in a splashproof housing. The computer ran a custom-written program which stored a GPS fix every 120 s to log distribution of sightings effort and (on pressing 'F1') recorded the date, time, and GPS fix of whale sightings and allowed keyboard input of other data. At the end of each day the two files (boat track and sightings) were transferred to a Macintosh computer for storage. A second palmtop was used for recording of blow intervals.

Fluke photographs were taken to identify whales individually (Arnbom 1987; Childerhouse & Dawson 1996). Photographs were taken with databack-equipped 35 mm cameras (Nikon F4S, F90×, F5) with 80–200 mm (f2.8) or 300 mm (f2.8 and f4) autofocus lenses, on Fujichrome 100 and Fuji Provia 100 slide film. All distances were measured with a laser range finder (Bushnell Yardage Pro 600, calibrated accuracy ± 1 m).

During June 1999, observations were made from the 15.3 m catamaran RV *Catalyst*. Observational protocol and equipment during this season were as described above, except that blow intervals were recorded directly on a Macintosh Powerbook 180.

2.1.2 Data collected

Weather

Weather data were recorded at the beginning of daily effort and whenever conditions changed. We recorded Beaufort state and wind direction as well as swell height and direction, all of which were estimated visually. Sighting conditions were estimated as being perfect, good, sufficient and unsuitable—depending on glare, visibility and light level. Effort was ended when Beaufort state exceeded 3 or sighting conditions were less than sufficient.

Whales

Whales were tracked with directional hydrophones of our own design and manufacture. An encounter began with the surfacing of a whale which had been tracked or with the spotting of a whale that had already surfaced. Position and time of surfacing (or spotting) was recorded. If the first blow after surfacing was detected, this was also recorded to ensure identification of encounters encompassing the full length of a sperm whale's surface time. The whale's initial heading was recorded relative to the lubber line of the boat compass. Blow intervals were timed if we were close enough to see blows reliably. Occurrence and kind of aerial behaviours (see section 2.4.3) were noted. When the whale fluked, time and GPS position were recorded and an ID photo taken. The whale's heading before fluking was also noted. In addition, the distance of the research vessel from the whale at the time of fluking was measured with the laser range finder. When conditions and available people allowed, we listened with the directional hydrophone to measure the elapsed time from fluke-up to first click.

Whale watching platforms

For the purpose of this analysis, the term 'whale watching platform' (WWP) comprises aircraft and boats and 'aircraft' includes fixed-wing planes and helicopters. For each encounter, presence of platforms was recorded. A boat was considered present when it had approached the same whale we were observing and, thereafter, remained approximately stationary relative to the whale. Typically, whale watching boats positioned themselves to the side and behind a whale. We recorded the names of all boats present. Aircraft were counted as present when they assumed a circular flying pattern above the observed whale.

Behaviour of research vessels

For this report, both *Cetos* and *Catalyst* are referred to as 'research vessel' (RV). The RV was handled in a consistent and unobtrusive way. The advantage of tracking the whale acoustically was that we were almost always within 500 m (usually much less) of the whale when it surfaced. Thus it was usually not necessary to travel fast to get within range, and we could manoeuvre the boat behind the whale at slow displacement speeds (3–5 knots). When a whale was spotted without tracking, it was often further away. To get within range we were often forced to travel faster (typically 15–20 knots). Once within 500 m we slowed to 3–5 knots.

Our standard practice was to approach from the side or the rear. Frontal approaches were accidental and occurred in less than 1% of encounters (11 in 1676 encounters) during this investigation.

After approaching, the boat was positioned behind the whale and kept at an approximately constant distance to the whale (typically 50 to 100 m), by adjusting boat speed to that of the whale. Only for the purpose of measuring whales (from *Cetos*) was the research vessel manoeuvred closer than 50 m, and in this case we manoeuvred alongside in order to gain side-on photographs showing the blowhole and dorsal fin with a pair of precisely aligned cameras (Dawson et al. 1995 for methods). Such approaches are analysed separately (see section 3.2).

2.2 LAND-BASED OBSERVATIONS

While we attempted to minimise disturbance due to the research vessel, our boat-based observations could not avoid its possibly confounding effects. In order to eliminate any such disturbance, we also conducted observations from land.

2.2.1 Equipment

Whales were spotted with a pair of high-powered Nikon binoculars (Nikon 18 × 70 IF WP WF on tripod) and time of each blow was recorded. Since fog, haze, wind and whitecaps make it difficult or impossible to spot blows reliably, observations ceased when these conditions prevailed. When sighting conditions allowed, the position of a spotted whale was fixed with a theodolite (Sokkisha TM 1A or a Kern DKM2-A, both equipped with 30× scopes). All data were stored on a palmtop computer (HP 200 LX) running custom-written software.

2.2.2 Data collected

A land-based observer is lucky if a whale happens to surface in the field of view of the binoculars. Thus, the first cue is typically a blow, and we could not usually be sure that the first blow was seen. Intervals between blows, and dive time were recorded for each whale spotted from land. Boats were recorded as present when they were close and stationary relative to the observed whale. Aircraft were recorded as present when they were flying a circular pattern above the observed whale. Often we had two teams, a hilltop team and a team out in *Cetos*, collecting data simultaneously. The hilltop team stopped collecting data if *Cetos* approached the same whale, to avoid double counting. Whenever possible, whales observed through the binoculars were also spotted through the theodolite and a fix of their position was taken.

2.3 ANALYSIS

Most data were not normally distributed; transformations were often necessary. We used:

$y_t = \ln(y)$, or $y_t = \sqrt{y}$, where y is the response variable and y_t is the transformed response variable.

Most data were analysed using General Linear Modeling methods (GLMs) in DataDesk 6.1 (Data Description Inc., Ithaca, NY, USA. The main factors considered for inclusion in the GLMs, along with their possible levels, were:

- Year (1998, 1999, 2000, 2001)
- Season (summer, autumn, winter, spring)
- ID (105 IDs)
- Whale watching platform presence (RV, RV+WWP, no vessel)

We first had to decide which of the above factors we should include in our analyses. Previous research indicated that sperm whales exhibit a seasonal difference in diving behaviour (Jaquet et al. 2000) and annual differences in residency of individuals (Childerhouse et al. 1995). Therefore, all models included year and season. We then had to decide whether to include ID and platform presence, and also whether interaction terms would be required. To do this in an objective and data-based manner, we used Aikaike's Information Criterion (AIC), an information-theoretic approach described by Burnham & Anderson (1998). This method measures two relative components for each model in a set of potential models: how closely a specific model describes the data and how complex that model is. The important point here is that model fit and complexity form a balance: a basic model, e.g. considering only season, will fit the data rather poorly, but will be simple and thus easy to interpret. In contrast, a complex model—one, for example, considering year, season, ID and platforms along with their interactions—will likely fit the data much better, but will also be much more difficult to interpret due to its numerous factors and combinations thereof. The ideal model, then, will be as simple as possible to describe the data adequately. The AIC facilitates such decisions by ranking all possible models according to their fit and complexity.

The tables presenting AIC results show the following information:

RSS: Residual Sum of Squares, a measure of the model fit

n: Sample size

K: Number of factors included in model, a measure of model complexity

Δ_i: Distance between i^{th} model and best model in set, a measure of how good each model is relative to other models in set; the best model has a distance value of zero

ω_i: Akaike weight of i^{th} model, a measure of how likely it is that the i^{th} model is indeed the best model given the data and the other models in the set; weights are scaled so that all weights for a set of models add up to one (due to rounding, sum of all weights may not equal one in tables)

In all AIC tables, the models are listed ranked from best to worst, i.e. the model with a Δ_i value of zero and with the largest ω_i value is provided in the first line of the table. This best model consequently will be used in GLM analyses to determine the influence of each factor on the data.

In a few cases, no transformation was able to normalise the data and non-parametric tests were used. Frequency data were analysed with log-likelihood ratio tests (2×2 G-tests with Williams' correction) or, if sample sizes were small, Fisher's Exact Test (Sokal & Rohlf 1981).

In order to address statistical concerns over pseudoreplication without losing too many data points, we divided the data into three subsets. The first set (Data Set 1) includes all data and thus did not consider whale ID since not all encounters contained ID information. The second set (Data Set 2) comprises only encounters with ID data. To reduce likelihood of pseudoreplication, the data for each individual were averaged by day and vessel presence. For example, if whale HL120 was seen five times during one day, two of the encounters being with RV, and three with RV+WWP, the data for analysis include two values: one being the mean of the RV encounters and the second the mean of the RV+WWP encounters. To account for the fact that these resulting means are computed from between one to three original data points, we weighted the means used in GLMs by the number of original data points. The third data set (Data Set 3) consisted of the same data points as Data Set 2, but contained information on the residency patterns of the particular animal. Thus, we used Data Set 3 to investigate responses by transient and resident individuals. All data in the final set (Data Set 4) were collected from shore. For some comparisons, this set was combined with data from one of the previous sets. If not noted otherwise, means are provided with standard errors. When descriptive statistics for non-normally distributed coefficients of variation or medians were required, distributions were first normalised and back-transformed means and 95% confidence intervals are provided. α was set at 0.05.

Because our on-board computer system recorded GPS fixes at regular intervals, we have detailed data on the location of search effort. Spatial analyses were standardised by search effort: the study area was divided into a grid of squares, each 1 km × 1 km, and time spent searching in, and the number of sightings, were summed for each square. The total number of sightings in each square was then divided by the total amount of time spent in that square. (Time was chosen as a measure of effort rather than distance travelled, since a considerable amount of time was spent tracking sperm whales while stationary. Therefore, distance would have underestimated total effort.) Sightings per minute were then plotted in ArcView 3.2® (ESRI, Redlands, Ca, USA).

2.4 DEFINITIONS

2.4.1 Season categories

Summer: Data collected during January and February

Autumn: Data collected during March and April

Winter: Data collected between June and August

Spring: Data collected during November and December

2.4.2 Encounter categories

Encounter (enc.): An encounter was scored when a sperm whale was spotted at the surface. If two sperm whales were sighted, two encounters would be logged unless the two whales were close (< 100 m) together and behaving in a coordinated fashion (e.g. turning in the same direction, diving at the same time).

Research vessel (RV): *Cetos* or *Catalyst* are referred to as research vessel. *Cetos* was used in all seasons except June 1999.

Whale watching platform (WWP): This term applies to all boats and aircraft used in the commercial whale watching activities off Kaikoura. If the type of platform is of particular interest, its name (in case of boat) or type (plane, helicopter) is mentioned.

Encounter with RV: Only the research vessel was within 300 m of the whale during an encounter. Abbreviation used in graphs and tables: RV.

Encounter without WWP: No boat or aircraft was with the observed whale during the duration of its surfacing. If the RV stayed more than 300 m from the whale during an encounter, this encounter was then considered an 'encounter without vessel'. Abbreviation used in graphs and tables: No platform.

Encounter with WWP: A minimum of one whale watching platform was present during at least part of the time the observed whale was at the surface. Encounters were not distinguished by the number and kind of WWP present. Sample size in some of the categories would have been too small for such analysis. Abbreviation used in graphs and tables: RV+WWP for boat-based observations, WWP for land-based observations.

2.4.3 Behaviours of sperm whales off Kaikoura (after Whitehead & Weilgart 1991)

Fluking: Whale raises its fluke above the water surface to an almost vertical position. Indicates the beginning of a foraging dive.

Shallow dive: Whale submerges without fluking.

Breach: Whale leaps partially or completely out of the water.

Head-out: Whale raises head partially or completely above water surface.

Lobtail: Whale thrashes fluke onto water surface.

Side-fluke: Whale turns on one side and partially lifts fluke out of the water.

Fluke-first: Whale breaks the surface with the fluke first, frequently holding it in almost perfectly vertical position.

2.4.4 Residency pattern of sperm whales off Kaikoura

Resident: A whale which was sighted in more than one season and/or during more than one day was considered a 'seasonal resident', following the definition by Jaquet et al. (2000). The updated sighting frequencies also showed a clear break between animals seen only once and those seen on more than one day (Fig. 2).

Transient: A whale which was seen only during one day was categorised as transient.

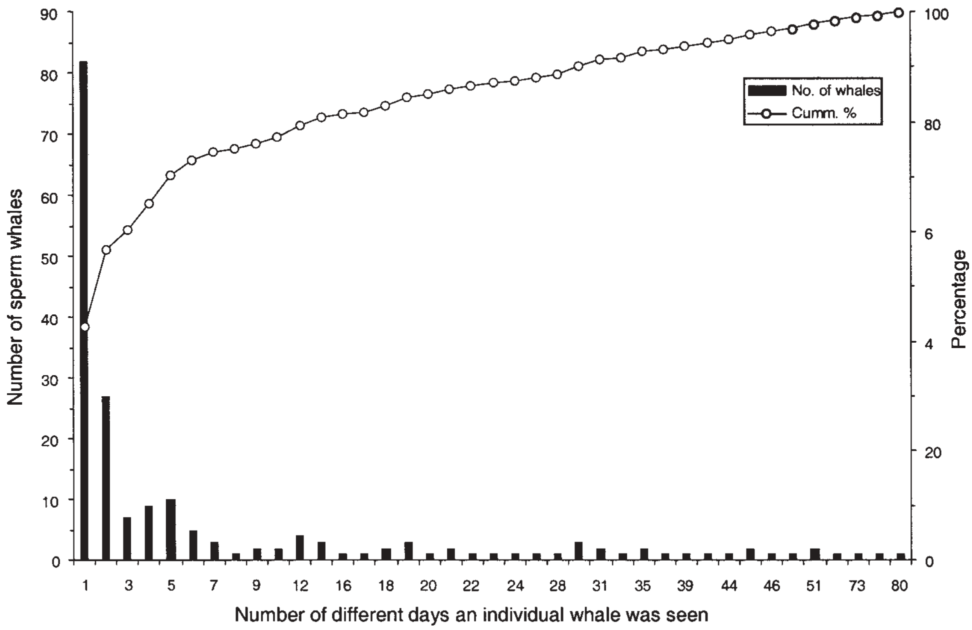


Figure 2. Frequency distribution of the number of days an individual whale was seen off Kaikoura along with the corresponding cumulative percentage.

2.4.5 Definition of data sets used in analyses

Data Set 1: includes all data. Information on whale ID was not considered in this data set.

Data Set 2: includes only data points with ID information. Response variables were averaged for each individual by day and vessel presence.

Data Set 3: Same as Data Set 2, but including also information on residency patterns of individual whales. This data set is used to investigate responses by residents and transients separately.

Data Set 4: includes all observations collected from shore.

3. Results

3.1 SUMMARY OF RESEARCH EFFORT

In total, we have carried out eight field seasons. Tables 1 and 2 summarise these seasons and provide an overview of our effort.

Encounter rate and the number of IDs gained per time (from our RV) were higher during the first two field seasons than in the following four seasons. They increased again slightly in the last three seasons (Fig. 3). In most (60–70%) of our boat-based encounters, in all seasons, our RV was the only boat present (Fig. 4).

From shore, the total proportion of encounters with and without WWPs was more equal (Fig. 5). However, the proportion differed among seasons; most sightings were without platforms during the first two seasons, and a majority of sightings were with platforms in the final field season (Feb. 2001). This largely reflected changing priorities as the study progressed. For example, in the beginning we were keen to get as much 'control' data as possible (no platforms at all) since that is only possible from the hilltop. So, if several whales were visible, we collected data from the one without whale watchers. Later in the study, to increase the amount of data collected while aircraft were overhead, we favoured those situations.

TABLE 1. SUMMARY OF THE BOAT-BASED EFFORT SPENT OFF KAIKOURA 1998–2001. ENCOUNTERS RELATE TO SIGHTINGS OF SPERM WHALES ONLY. THE NUMBER OF IDS INCLUDES ONLY ENCOUNTERS DURING WHICH WE OBTAINED A SUITABLE PHOTO ID OF THE WHALE.

SEASON	NUMBER OF DAYS	TOTAL HOURS	NUMBER OF ENCOUNTERS	NUMBER OF IDS
Nov/Dec 98	22	162	379	286
Feb 99	21	168	353	280
Jun 99	16	83.6	111	49
Nov/Dec 99	14	79.8	119	74
Mar/Apr 00	16	113.9	162	85
Jun 00	13	76.3	118	87
Nov/Dec 00	23	134.1	209	131
Feb 01	20	145.2	225	172
Total	145	962.7	1676	1164

TABLE 2. SUMMARY OF LAND-BASED EFFORT OFF KAIKOURA 2000–2001.

SEASON	NUMBER OF DAYS	TOTAL HOURS	NUMBER OF ENCOUNTERS
Mar/Apr 00	10	27	36
Jun 00	6	55.8	104
Nov/Dec 00	13	69.7	104
Feb 01	16	91.8	191
Total	45	244.3	435

Figure 3. Mean seasonal rate of encounters and ID per hour (error bars = ± 1 SD) (Enc. = encounter).

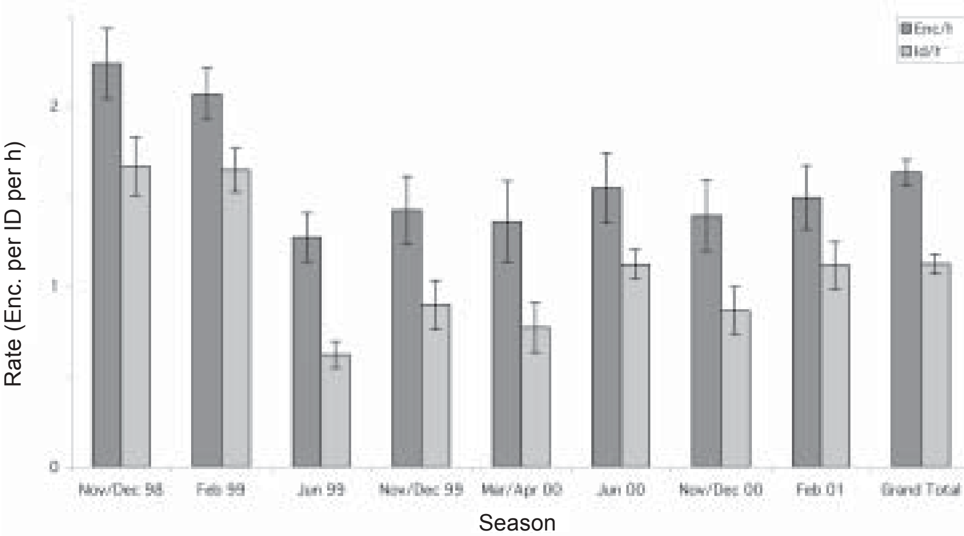


Figure 4. Seasonal proportion of boat-based encounters with and without WWPs. Numbers above bars represent sample sizes.

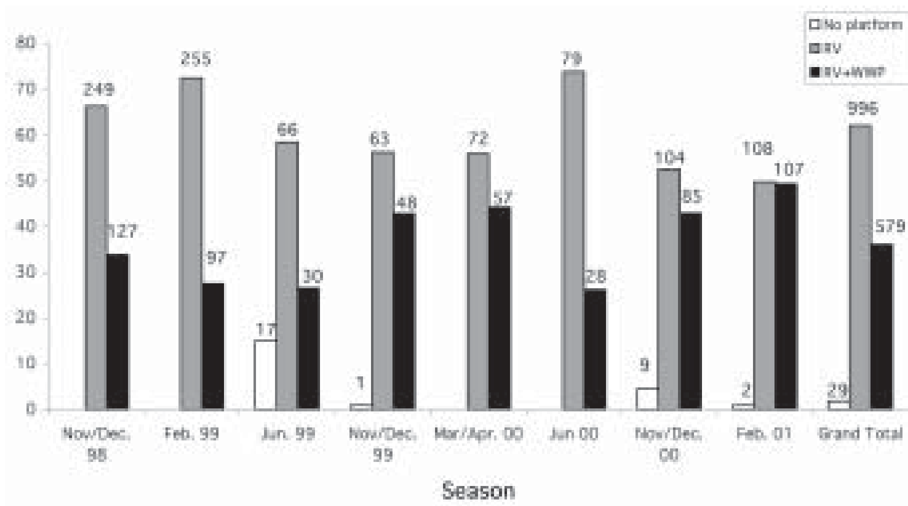
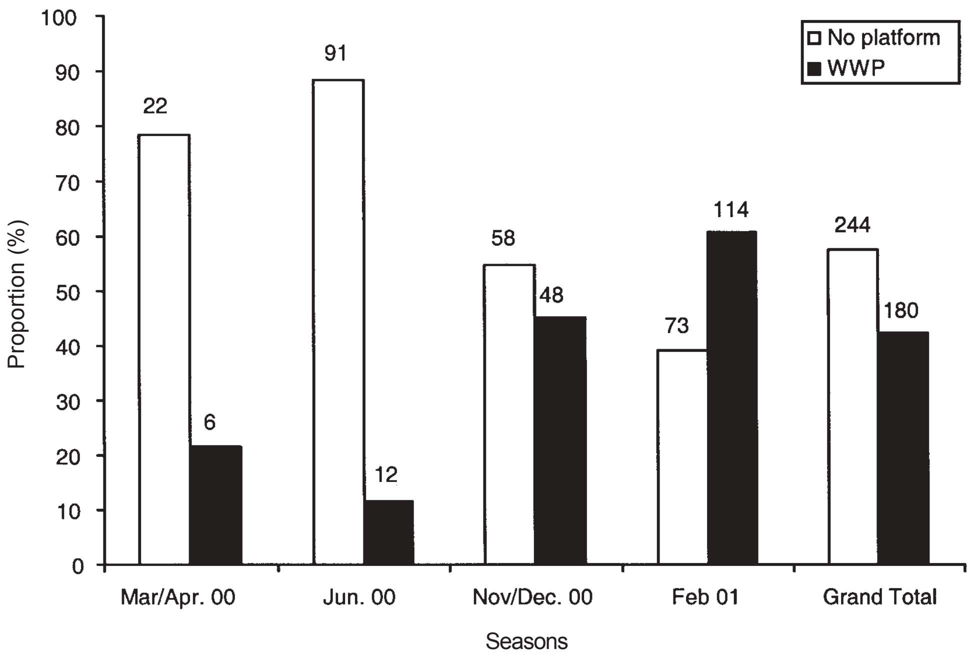


Figure 5. Seasonal proportion of shore-based encounters with and without WWboats. Numbers above bars represent sample sizes.



3.2 REACTIONS TO APPROACHES FOR STEREO-PHOTOGRAPHY

3.2.1 Definition

For purpose of photogrammetric length measurements, we occasionally approached whales to take stereo-pictures (Dawson et al. 1995). This required *Cetos* to be alongside and close to the whale (< 50 m) until three pairs of pictures were taken. We then maneuvered the boat slowly to the normal position behind the whale. Stereo-approaches were never carried out when WWPs were present. Since these approaches did not conform with the regular behaviour of *Cetos* around whales, we investigated whether the whales' responses to these approaches differed from those to normal RV encounters.

3.2.2 Results

Twenty-eight stereo approaches were carried out. Only resident animals were involved in successful attempts. Blow intervals were not significantly affected by stereo approaches. Similarly, neither mean blow interval, coefficient of variation, mode of blow interval nor number of blows showed significant differences. The same results were obtained for absolute change in direction, time to first click and surface time (Table 3).

TABLE 3. SUMMARY OF EFFECTS OF STEREO APPROACHES ON BEHAVIOURAL PARAMETERS.

PARAMETER	TEST	d.f.	F-RATIO	p-VALUE
Mean blow interval	GLM	1	1.38	0.24
Blow interval median	GLM	1	0.03	0.87
CV of mean blow interval	GLM	1	2.63	0.11
Mean number of blows	GLM	1	0.10	0.75
Time to first click	GLM	1	2.06	0.15
Change of heading	Mann-Whitney U	–	–	0.10
Frequency of heading change	2×2 G	–	–	0.10
Surface time	GLM	1	0.36	0.55

3.2.3 Conclusion

Resident whales did not respond significantly to the closer and side-on approach necessary for stereo-photography. We acknowledge, however, that statistical power to detect effects is compromised by relatively low sample size (caused by stereo-photography not having a high priority in this investigation). All successful attempts were with resident whales. On five occasions, attempts to stereo-photograph transients were abandoned because the whale continually turned away from the vessel. Since these approaches were not successful, they are not included in the above analysis. Thus, considering the low sample size of the analysis and the potential effect of these approaches on transient individuals, we excluded encounters with stereo approaches from further analyses. This exclusion also ensured that the behaviour of the RV was as consistent and predictable as possible for the following comparisons.

3.3 THE IMPACT OF WHALE WATCH PLATFORMS ON SPERM WHALES

3.3.1 Ventilation patterns

Data available for analysis

Data on breathing patterns were collected from the RV for 1211 encounters, totalling 31 741 blow intervals. Information on the ID of the whale was available for about three-quarters of the encounters (n = 913). This data set includes sightings of 105 different whales, comprising 55% of the current ID catalogue (n = 190). From shore, we logged 424 encounters, encompassing 8811 blow intervals. These data are summarised in Table 4.

TABLE 4. SUMMARY OF DATA ON VENTILATION PATTERNS COLLECTED FROM THE RV AND SHORE (MEAN (CV)).

VARIABLE	DATA SET	RV	SHORE
Blow interval (seconds)			
	Data Set 1 (boat: n = 1175; shore: n = 424)	16.5 (36.42)	16.7 (27.55)
	Data Set 2 (boat: n = 885)	15.8 (18.99)	–
	Data Set 3: Residents only (boat: n = 829)	15.8 (18.61)	–
	Data Set 3: Transients only (boat: n = 56)	15.0 (22.73)	–
CV of blow mean (seconds)			
	Data Set 1 (boat: n = 1175; shore: n = 423)	23.8 (50.00)	24.9 (48.43)
	Data Set 2 (boat: n = 885)	22.5 (43.82)	–
	Data Set 3: Residents only (boat: n = 829)	22.4 (44.24)	–
	Data Set 3: Transients only (boat: n = 56)	23.8 (37.86)	–
Blow interval median (seconds)			
	Data Set 1 (boat: n = 1175; shore: n = 381)	16.0 (31.00)	16.2 (27.76)
	Data Set 2 (boat: n = 855)	15.5 (17.81)	–
	Data Set 3: Residents only (boat: n = 575)	15.5 (17.41)	–
	Data Set 3: Transients only (boat: n = 39)	15.3 (23.33)	–
Number of blows per surfacing			
	All data (boat: n = 521)	30.8 (34.36)	–
	Data with ID (boat: n = 313)	23.9 (38.26)	–
	Data Set 3: Residents only (boat: n = 388)	32.4 (29.75)	–
	Data Set 3: Transients only (boat: n = 23)	35.5 (29.92)	–

Model selection: which models best fit the data?

The focus of this section is to evaluate, using AICs, which combination of variables best fits each data set.

Data Set 1

Comparing among models using AICs indicated that vessel presence was not necessary to explain variation in blow intervals, mode and CV. None of the best models (i.e. $\Delta_i = 0$) for these response variables included vessel as a necessary factor. However, analysing number of blows required vessel presence to be included (Table 5).

TABLE 5. AIC ANALYSIS OF BLOW INTERVAL CHARACTERISTICS USING DATA SET 1.
Within each response variable, models are given in order of preference, as ranked using AICs. + signs in model name indicate model without interactions, × signs indicate model with interactions. (RSS = residual sums of squares; K = number of factors included in i^{th} model; Δ_i = distance of i^{th} model to best model in set; ω_i = Akaike weight of i^{th} model). (2-way) indicates that only interactions between two main factors were considered. **All subsequent tables presenting AIC analyses have the same structure and use the same symbols. Please refer to this table for explanations.**

RESPONSE VARIABLE	FACTORS	RSS	n	K	Δ_I	ω_I
Mean blow interval						
	Year×Season	62.18	1174	4	0	0.98
	Year+Season	62.68	1174	3	7.4	0.02
	Year×Season×WWP	61.06	1161	8	38.09	≤ 0.00
	Year+Season+WWP	62.11	1161	4	46.9	≤ 0.00
Blow median						
	Year×Season	58.39	1171	4	0	0.97
	Year+Season	58.83	1171	3	6.79	0.03
	Year×Season×WWP	57.05	1158	8	33.02	≤ 0.00
	Year+Season+WWP	58.17	1158	4	47.554	≤ 0.00
CV of blow mean						
	Year+Season	187.95	1174	3	0	0.73
	Year×Season	187.94	1174	4	1.95	0.27
	Year+Season+WWP	184.89	1161	4	19.65	≤ 0.00
	Year×Season×WWP	183.83	1161	8	21.00	≤ 0.00
Mean number of blows						
	Year×Season×Platform (2-way)	53158.50	521	8	0	0.81
	Year×Season	54322.40	521	4	3.28	0.16
	Year+Season+WWP	54707.80	521	4	6.97	0.003
	Year+Season	55306.10	521	3	10.63	≤ 0.00

Data Set 2

AIC analysis of the data set including IDs and with response variables averaged by individual, day and vessel presence required the inclusion of vessel presence in the models without exception. Best models (i.e. Δ_i = 0) for all analyses were the full models with interactions (Table 6).

Data Set 3

Data Set 3 was analysed using only platform presence as a factor for two reasons. Since Data Set 3 contains the same data as Data Set 2, no new AIC analysis was carried out. Furthermore, by using Data Set 3, we were chiefly interested in whether residents and transients responded differently to the presence of WWPs and not in determining the most influential factor (which has been accomplished already with the analysis of Data Set 2).

Data Set 4

Shore-based data were best explained by models including both season and vessel presence (year was not included in this analysis since observations were carried out only in two years) (Table 7). Number of blows per surfacing was not analysed because we could not be sure of having seen the first blow.

TABLE 6. AIC ANALYSIS OF BLOW INTERVAL CHARACTERISTICS USING DATA SET 2. See Table 5 for symbol explanations.

RESPONSE VARIABLE	FACTORS	RSS	n	K	Δ_I	ω_I
Mean blow interval						
	Year×Season×ID×WWP (2-way, no Year×Season)	9.09	617	11	0	1.00
	Year×Season×ID (2-way, no Year×Season)	9.74	617	7	34.61	≤ 0.00
	Year+Season+ID	12.36	617	4	175.60	≤ 0.00
	Year+Season+ID+WWP	12.36	617	5	177.60	≤ 0.00
CV of blow mean						
	Year×Season×ID×WWP (2-way, no Year×Season)	50.26	585	11	0	1.00
	Year×Season×ID (2-way, no Year×Season)	54.69	585	7	41.42	≤ 0.00
	Year+Season+ID+WWP	63.56	585	5	125.34	≤ 0.00
	Year+Season+ID	63.97	585	4	127.10	≤ 0.00
Blow median						
	Year×Season×ID×WWP (2-way)	12.28	615	11	0	1.00
	Year×Season×ID (2-way)	12.97	615	7	25.62	≤ 0.00
	Year+Season+ID	15.99	615	4	148.35	≤ 0.00
	Year+Season+ID+WWP	15.94	615	5	148.43	≤ 0.00
Mean number of blows						
	Year×Season×ID×WWP (2-way)	8530.9	313	11	0	1
	Year+Season+ID	15777.6	313	4	178.46	≤ 0.00
	Year+Season+ID+WWP	15734.2	313	5	179.60	≤ 0.00
	Year×Season×ID (2-way)	102224.0	313	7	769.33	≤ 0.00

TABLE 7. AIC ANALYSIS OF BLOW INTERVAL CHARACTERISTICS USING DATA SET 4. See Table 5 for symbol explanations.

RESPONSE VARIABLE	FACTORS	RSS	n	K	Δ_I	ω_I
Mean blow interval						
	Season×WWP	18.20	424	4	0	0.60
	Season+WWP	18.35	424	3	1.48	0.29
	Season	18.52	424	2	3.45	0.10
CV of blow mean						
	Season×WWP	76.84	424	4	0	0.75
	Season+WWP	77.71	424	3	2.80	0.19
	Season	78.47	424	2	4.91	0.06
Blow median						
	Season×WWP	18.22	424	4	0	0.82
	Season+WWP	18.47	424	3	3.78	0.12
	Season	18.62	424	2	5.21	0.06

Which factors are most important?

In the previous section we established which model best fitted each data set. In this section we explore the preferred model (for each data set) to allow judgement of which factors, or combinations of them, are most important. This is done by looking at the GLM results.

Data Set 1

GLM analysis of this data set showed no significant effect of vessel presence except for the medium of blow intervals (Table 8). Year and season were the dominant influences. The mode was influenced mainly by interactions of vessel with both year and season.

Data Set 2

Variation caused by individual differences among whales was large, swamping the effects of other factors in GLM analyses (Table 9).

Data Set 3: Comparisons between residents and transients

Characteristics of ventilation patterns of residents and transients were not significantly altered by presence of WWPs, but this comparison is severely compromised by the low sample size of transients for which a complete surfacing period was observed (n = 20). In general, transients were rarely visited by WWPs. In addition, obtaining complete surfacings typically involved tracking the whale prior to it surfacing. Therefore, another WWP was rarely present when we were observing a transient which we had tracked. Nevertheless, there is an indication of a difference in the number of blows

TABLE 8. SUMMARY OF RESULTS OF GLM ANALYSES ON BLOW INTERVAL CHARACTERISTICS USING DATA SET 1.

(Ln(mean/mode/CV) denotes that the corresponding response variable was transformed using the natural logarithm.) Significant p-values are marked in bold. PV = percentage of variance explained by effects (Murphy & Myors 1998); f = measure of effect magnitude, f = 0.1 is a small effect, f = 0.25 is a medium effect, f = 0.4 is a large effect (Kirk 1996). **All subsequent tables presenting GLM analyses have the same structure and use the same symbols. Please refer to this table for explanations.**

RESPONSE VARIABLE	FACTORS	d.f.	F-RATIO	p-VALUE	PV	f
Ln(mean)						
	Year	3	11.77	**≤ 0.001**	2.82	0.16
	Season	3	15.55	**≤ 0.001**	1.45	0.11
	Year×Season	1	9.37	**0.002**	0.78	0.08
Ln(CV)						
	Year	3	15.54	**≤ 0.001**	4.47	0.21
	Season	3	6.67	**≤ 0.001**	1.94	0.13
	Year×Season	2	0.48	0.62	0.12	0.02
Ln(median)						
	Year	2	11.60	**≤ 0.001**	2.21	0.16
	Season	3	5.81	**≤ 0.001**	3.28	0.19
	Year×Vessel	1	18.12	**≤ 0.001**	3.41	0.21
Number of blows						
	Year	2	2.79	0.06	1.09	0.08
	Season	3	4.91	**0.002**	2.83	0.15
	Year×Season	1	9.04	**0.003**	1.75	0.12
	WWP	2	0.62	0.54	0.24	0.04
	Year×WWP	2	0.46	0.63	0.25	0.04
	Season×WWP	3	0.87	0.46	0.51	0.03

TABLE 9. SUMMARY OF RESULTS OF GLM ANALYSES ON BLOW INTERVAL CHARACTERISTICS USING DATA SET 2.
See Table 8 for symbol explanations.

RESPONSE VARIABLE	FACTORS	d.f.	F-RATIO	p-VALUE	PV	f
Ln(mean)						
	ID	98	2.20	**≤ 0.001**	35.29	0.43
	Season	3	0.34	0.80	0.26	0.07
	ID×Season	20	1.33	0.16	6.42	0.13
	Year	3	1.17	0.32	0.90	0.04
	ID×Year	54	1.10	0.32	13.26	0.11
	Season×Year	1	0.11	0.75	0.03	0.05
	WWP	2	0.41	0.66	0.21	0.05
	ID×WWP	44	0.55	0.99	5.91	0.22
	Season×WWP	3	1.66	0.18	1.27	0.07
	Year×WWP	3	0.21	0.89	0.69	0.03
Ln(CV)						
	ID	95	0.95	0.62	20.05	0.11
	Season	3	1.19	0.32	0.99	0.04
	ID×Season	19	0.65	0.87	4.41	0.08
	Year	3	0.52	0.67	0.43	0.06
	ID×Year	53	0.84	0.78	11.06	0.15
	Season×Year	1	2.37	0.12	0.66	0.06
	WWP	2	1.11	0.33	0.61	0.02
	ID×WWP	44	0.62	0.97	7.11	0.20
	Season×WWP	3	0.53	0.66	0.44	0.06
	Year×WWP	3	0.25	0.86	0.21	0.08
Ln(median)						
	ID	98	1.60	**0.001**	29.02	0.38
	Season	3	1.24	0.30	0.96	0.04
	ID×Season	20	1.23	0.23	6.04	0.11
	Year	3	1.49	0.22	1.15	0.06
	ID×Year	54	0.83	0.80	10.48	0.15
	Season×Year	1	0.25	0.62	0.06	0.04
	WWP	2	0.34	0.71	0.18	0.06
	ID×WWP	44	0.37	1.00	4.02	0.26
	Season×WWP	3	1.97	0.12	1.52	0.08
	Year×WWP	3	0.10	0.96	0.08	0.08
Number of blows						
	ID	71	2.60	**≤ 0.001**	54.97	0.53
	Season	3	0.33	0.81	0.65	0.07
	ID×Season	13	1.13	0.34	8.87	0.07
	Year	2	0.90	0.41	1.18	0.02
	ID×Year	34	1.65	**0.02**	27.09	0.23
	Season×Year	1	0.14	0.71	0.09	0.05
	WWP	1	0.22	0.64	0.14	0.04
	ID×WWP	31	0.67	0.90	12.09	0.16
	Season×WWP	3	1.52	0.21	0.42	0.08
	Year×WWP	2	0.28	0.76	0.37	0.06

(Table 10). Residents blew 31.6 ± 0.69 (n = 172) times per surfacing with only the RV present. With the WWP present, number of blows increased to 33.4 ± 0.82 (n = 121). By contrast, transients reduced their number of blows from 37.3 ± 2.36; (n = 18) with only the RV present to 23 (n = 2) in the presence of the WWP. The effect of other variables was much less.

TABLE 10. SUMMARY OF RESULTS OF GLM ANALYSES ON NUMBER OF BLOWS PER SURFACING USING DATA SET 3, ANALYSING RESPONSES TO WWPS BY RESIDENTS AND TRANSIENTS.
See Table 8 for symbol explanations.

DATA SET	RESPONSE VARIABLE	d.f.	F-RATIO	p-VALUE	PV	f
Residents						
	Ln(mean)	1	0.43	0.65	0.08	0.04
	Ln(CV)	1	1.96	0.14	0.18	0.01
	Ln(median)	1	0.60	0.55	0.10	0.03
	Number of blows	1	3.81	0.05	1.29	0.08
Transients						
	Ln(mean)	1	0.01	0.93	0.02	0.05
	Ln(CV)	1	0.66	0.42	1.81	0.03
	Ln(median)	1	0.04	0.85	1.01	0.04
	Number of blows	1	3.05	0.10	14.48	0.07

Data Set 4

From shore, encounters were either with a boat or without any boat (encounters during which the RV approached were terminated). Four hundred and twenty-four encounters were observed of which 58% (n = 244) were without boats present. These encounters had a mean blow interval of 16.9 ± 0.24 s (range 10–36.9 s). Encounters with WWPs had a mean interval of 16.4 ± 0.42 s (range 10.6–59.2 s; n = 180). GLM analysis of these observations showed an effect of WWP presence on mean blow interval barely above the significance level, and a significant effect on the median of blow intervals (Table 11). Whales reduced median blow interval from 16.0 s (95% C.I. = 15.60–16.38 s; n = 244) without WWPs to 15.5 s (95% C.I. = 14.93–15.99 s; n = 180) with WWPs. However, effect size was typically small (see PV values; Table 11).

3.3.2 Surface time

Data available for analysis

For analysis of the time whales spent at the surface, only encounters during which the first blow was detected could be included. In total, 794 such encounters were recorded, 28% of which included ID information (n = 221). The overall mean surface time was 8.7 ± 0.17 min. The shortest surface time recorded was 0.1 min, while the longest surface time was 53.3 min.

TABLE 11. SUMMARY OF RESULTS OF GLM ANALYSES ON BLOW INTERVAL CHARACTERISTICS USING DATA SET 4.
See Table 8 for symbol explanations.

RESPONSE VARIABLE	FACTORS	d.f.	F-RATIO	p-VALUE	PV	f
Ln(mean)						
	WWP	1	3.82	0.05	0.91	0.08
	Season	3	1.26	0.29	0.90	0.04
Ln(CV)						
	WWP	1	0.35	0.55	0.09	0.04
	Season	3	0.89	0.55	0.64	0.03
	WWP×Season	3	1.58	0.19	1.13	0.06
	WWP×Season	3	1.14	0.33	0.82	0.03
Ln(median)						
	WWP	1	4.32	**0.04**	1.03	0.09
	Season	3	1.41	0.24	1.01	0.06
	WWP×Season	3	1.92	0.13	1.36	0.08

Model selection: which models best fit the data?

The focus of this section is to evaluate, via AICs, which combination of variables best fits each data set. For Data Set 1, the variables year, season and WWP, with no interaction term, provided the best model. In contrast, when Data Set 2 was used, the full model with 2-way interactions was the most appropriate model (Table 12).

TABLE 12. AIC ANALYSIS OF SURFACE TIME.
See Table 5 for symbol explanations.

DATA SET	FACTORS	RSS	n	K	Δ_I	ω_I
Data Set 1						
	Year+Season+WWP	467.23	793	4	0	0.75
	Year×Season×WWP	463.81	793	8	2.18	0.25
	Year+Season	476.80	793	3	14.08	≤ 0.00
	Year×Season	475.76	793	4	14.36	
Data Set 2						
	Year×Season×ID×WWP (2-way)	11.17	327	11	0	1
	Year×Season×ID (2-way)	13.90	327	7	≤ 0.00	≤ 0.00
	Year+Season+ID	19.00	327	4	≤ 0.00	≤ 0.00
	Year+Season+ID+WWP	18.99	327	5	≤ 0.00	≤ 0.00

GLM Analysis: which factors are most important?

In this section we explore the preferred model (for each data set) to allow judgement of which factors, or combinations of them, are most important.

Data Set 1

For Data Set 1, the only significant factor was WWP presence (Table 13). Surface time with and without WWPs was 9.2 ± 0.26 min (n = 248) and 8.4 ± 0.22 min (n = 545), respectively.

TABLE 13. SUMMARY OF RESULTS OF GLM ANALYSES ON SURFACE TIME. THE RESPONSE VARIABLE IN DATA SET 1 WAS TRANSFORMED USING SQUARE-ROOT. See Table 8 for symbol explanations.

DATA SET	FACTORS	d.f.	F-RATIO	p-VALUE	PV	f
Data Set 1						
	Year	3	2.20	0.09	0.83	0.07
	Season	2	0.59	0.55	0.15	0.03
	WWP	1	10.93	**0.001**	1.37	0.11
Data Set 2						
	ID	74	2.16	≤ **0.001**	49.82	0.46
	Season	3	0.86	0.46	1.58	0.03
	ID×Season	13	1.21	0.28	8.90	0.08
	Year	2	1.78	0.17	2.16	0.06
	ID×Year	34	1.80	**0.008**	27.54	0.26
	Season×Year	1	0.04	0.85	0.03	0.05
	WWP	1	1.62	0.20	1.00	0.04
	ID×WWP	32	1.02	0.45	16.83	0.04
	Season×WWP	3	3.83	**0.01**	6.66	0.15
	Year×WWP	2	0.80	0.45	0.99	0.03

Data Set 2

When Data Set 2 was used, ID and interactions with it were the significant main factors (Table 13). In addition, the interaction between platform and season was significant.

Data Set 3: Comparison between residents and transients

The data seem to suggest that residents and transients responded differently to the presence of WWPs. While surface time for residents remained virtually unchanged (RV: 9.3 ± 0.23 min; n = 182; RV+WWP: 9.2 ± 0.20 min; n = 122), transients reduced time spent at the surface from 9.7 ± 0.74 min (n = 21) in the presence of RV to 7.0 ± 0.77 min (n = 2) when WWPs took part in the encounter. Neither of these changes are significant (Table 14). This is not surprising in the case of transient individuals, considering that we had only two encounters between them and WWPs for which we were able to observe the first blow.

TABLE 14. SUMMARY OF RESULTS OF GLM ANALYSES ON EFFECTS OF VESSEL PRESENCE ON SURFACE TIME USING DATA SET 3, COMPARING RESPONSES BY RESIDENTS AND TRANSIENTS.
See Table 8 for symbol explanations.

DATA SET	FACTORS	d.f.	F-RATIO	p-VALUE	PV	f
Residents						
	WWP	1	0.76	0.39	0.19	0.02
Transients						
	WWP	1	1.42	0.25	6.34	0.14

3.3.3 Directional heading

Analysis of all available data

Directional heading was analysed in two ways. First, the frequency of encounters during which a change in heading occurred (i.e. change in absolute heading > 10°) was analysed for influence of WWP presence. Since heading change can be measured only from the RV, all data include a potential effect of the RV. If WWPs have no extra effect, the ratio of no direction changes (< 10°) to direction changes (> 10°) for the RV should be the same as when WWPs are present also. Second, absolute change in heading was compared between RV encounters and WWP encounters. This was calculated by subtracting the first compass heading of an encounter from the last heading just before fluking. The absolute value of this difference was used in the analyses and should be approximately the same if WWPs have no effect.

Data Set 1

Using Data Set 1, whales responded significantly to the presence of WWPs by turning more frequently (Table 15). Similarly, WWP presence significantly affected the magnitude of heading change (Table 16). Mean heading change during RV encounters increased from 25.2° to 30.4° change during RV+WWP encounters (Table 16).

TABLE 15. SUMMARY OF ANALYSIS OF FREQUENCY OF HEADING CHANGE IN RESPONSE TO THE PRESENCE OF WWPS.
Tests were 2×2 G-test for residents and Fisher's Exact Test for transients. Numbers in parentheses give column percentages for each data set.
See Table 8 for symbol explanations.

DATA SET	ENCOUNTER	RV	RV+WWP	p-VALUE
Data Set 1				
	< 10°	491 (72)	242 (63)	**< 0.01**
	> 10°	195 (28)	141 (37)	
Data Set 3: Residents				
	< 10°	347 (71)	197 (64)	**0.04**
	> 10°	149 (29)	110 (36)	
Data Set 3: Transients				
	< 10°	39 (78)	4 (50)	0.11
	> 10°	11 (22)	4 (50)	

TABLE 16. SUMMARY OF AMOUNT OF HEADING CHANGE (+ S.E.) IN RESPONSE TO THE PRESENCE OF WWPS.
Tests were Mann-Whitney U tests without ties. (Since the Mann-Whitney U test ranks the values in a data set, ties between the same data values are possible. Inclusion of such ties violates some assumptions and necessitates estimation of the test statistic. To avoid this, ties were not included in any analysis employing this test.)
See Table 8 for symbol explanations.

DATA SET	RV	RV+WWP	p-VALUE
Data Set 1 (n = 1101)	25.2 ± 2.25°	30.4 ± 3.28°	**< 0.01**
Data Set 2 (n = 605)	24.2 ± 2.68°	29.4 ± 3.62°	0.68
Data Set 3: Residents (n = 562)	24.7 ± 2.90°	29.2 ± 3.73°	0.80
Data Set 3: Transients (n = 41)	17.3 ± 5.91°	32.5 ± 10.13°	0.19

Data Set 2

It is not useful to compute daily averages of whether heading changes occurred. Therefore, we can use Data Set 2 only in the analysis of mean heading change, which did not show significant effects of WWPs (Table 16).

Data Set 3: Comparison between residents and transients

The additional presence of WWPs caused significantly more direction changes for residents (p = 0.037) but not for transients (p = 0.11) (Table 15). However, transients changed direction in half the encounters with WWPs, but in only 22% of the encounters with the RV, suggesting a real difference in reactions. If this difference was consistent, we would have needed to see 26 interactions between transients and WWPs for statistical significance (p = 0.05) to be reached with a statistical power of 0.80.

Residents changed heading on average 24.7° with the RV only. The increase to 29.2° when WWPs were present was not significant (Table 16). Transient whales seemed to respond more to the presence of WWPs. They turned on average 17.3° with RV and 32.5° with WWPs. This difference was not significant.

3.3.4 Aerial behaviour

Instances of aerial behaviour were recorded in 163 encounters. Aerial behaviour was more common during RV encounters compared with WWP encounters (Table 17). Statistical comparison was not possible for transient whales since aerial behaviours were recorded only on two occasions.

3.3.5 Consecutive encounters with and without WWPs

Consecutive encounters were defined as encounters which had consecutive encounter numbers in the sightings file and/or had fluke times less than two average dive durations (= 80 min) apart. Of all encounters collected between 1998 and 2001, 415 fulfilled this criterion, resulting in 174 groups of between two and eight consecutive encounters. Most of these (42%, n = 74) included RV and RV+WWP encounters. The remaining groups consisted only of RV encounters (38%, n = 66) or WWP encounters (20%, n = 34). For analysis, encounters were divided into the following transition categories:

TABLE 17. SUMMARY OF ANALYSIS OF FREQUENCY OF AERIAL BEHAVIOURS IN RESPONSE TO THE PRESENCE OF WWPS.
Tests were 2×2 G-test. Numbers in parentheses give column percentages for the corresponding comparison. See Table 8 for symbol explanations.

DATA SET	RESPONSE	RV	RV+WWP	p-VALUE
Data Set 1				
	No aerial behaviour	954 (88.5)	565 (93.5)	
	Aerial behaviour	124 (11.5)	39 (6.5)	**0.001**
Data Set 3: Residents				
	No aerial behaviour	560 (91)	379 (95)	
	Aerial behaviour	54 (9)	21 (5)	**0.003**
Data Set 3: Transients				
	No aerial behaviour	50 (96)	9 (100)	–
	Aerial behaviour	2 (4)	0	

RV–WWP: transition from an encounter with RV to a WWP encounter (similar to a 'before-during' comparison)

WWP–RV: transition from an encounter with WWP to a RV encounter (similar to a 'during-after' comparison)

Analysis for blow intervals was carried out by subtracting the interval of the 'RV-encounter' from that of the 'WWP-encounter' (RV–WWP comparison) and, similarly, the interval from the 'WWP-encounter' was subtracted from the 'RV-encounter' (WWP–RV comparison). It was then determined whether these differences were negative or positive and the frequency of occurrence of each was tallied for RV–WWP and WWP–RV comparisons. Analysis for surface intervals followed this method; however, only encounters with the 1st blow were included in the analysis. While sperm whales did not change their blow intervals before or after encounters with WWPs (Table 18 and Fig. 6), they increased their time at the surface when WWPs were present in the second encounter. However, surface times of encounters following a WWP encounter were usually shorter than those with WWPs (Table 18 and Fig. 7).

TABLE 18. FREQUENCY OF POSITIVE AND NEGATIVE CHANGES OF BLOW INTERVALS AND SURFACE TIME. ONLY CONSECUTIVE ENCOUNTERS WITH A CHANGE OF VESSEL PRESENCE WERE CONSIDERED. Numbers in parentheses give column percentages for the corresponding comparison. Tests were 2×2 G-tests.

	RV–WWP	WWP–RV	p-VALUE
Blow Interval			
Negative change	16 (44)	20 (47)	
Positive change	20 (56)	23 (53)	p = 0.86
Surface time			
Negative change	5 (33)	8 (73)	
Positive change	10 (67)	3 (27)	p = 0.05

3.3.6 Time to first click

Data available for analysis

Information on time to first click was available for 620 encounters. Of these, 16 were stereo approaches and were not used for analyses. If whales had not started clicking after more than 10 minutes we usually terminated the encounter. This occurred on eight occasions. Thus, 596 data points were available for analysis. Mean time to first click was 29.5 ± 1.50 s (range 1–540 s).

Model selection: which model best fits the data?

For both Data Sets 1 and 2, the best model included presence of WWPs, and an interaction between WWPs, year and season (Table 19).

GLM analysis: which factors are most important?

Data Set 1

All main factors were significant in the GLM in addition to some interaction terms (Table 20). In response to WWPs, whales reduced the time to first click from 33.3 ± 2.19 s (n = 355) to 23.6 ± 1.32 s (n = 240).

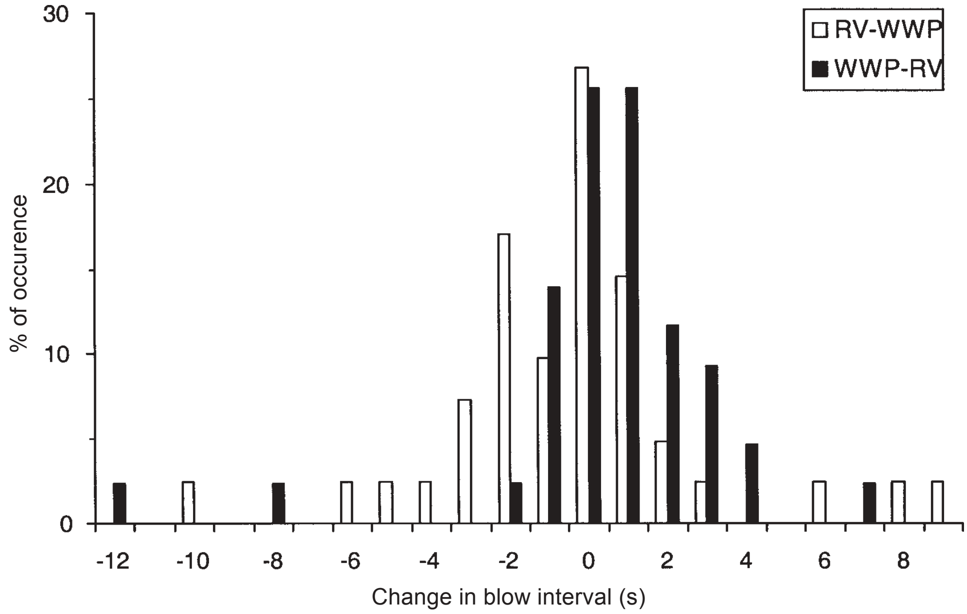


Figure 6. Frequency distribution of changes in blow intervals (seconds) in transitions of RV–WWP encounters and of WWP–RV encounters.

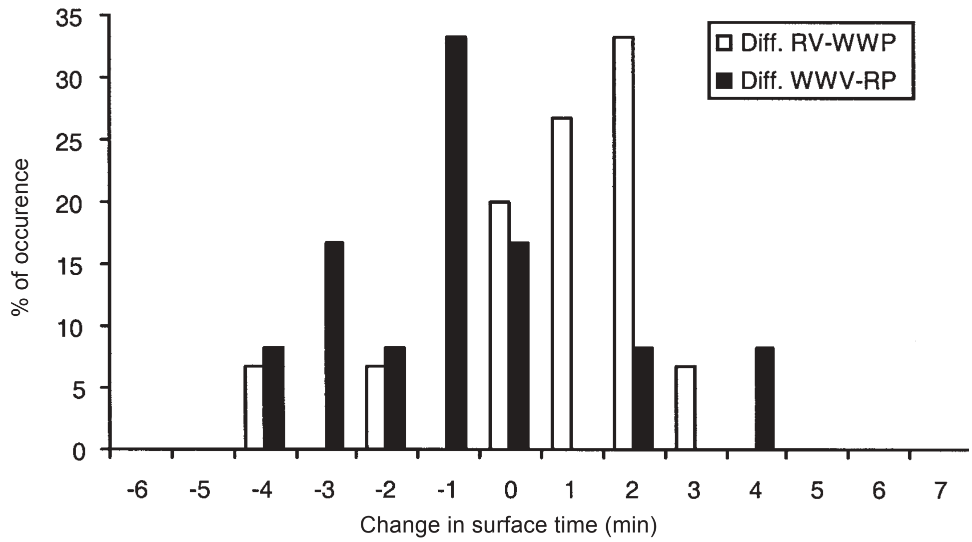


Figure 7. Frequency distribution of changes in surface time (minutes) in transitions of RV–WWP encounters and of WWP–RV encounters.

Data Set 2

When Data Set 2 was investigated, only ID was significant (Table 20), indicating that variability due to individual differences again swamped the effect of everything else. In this comparison, whales took 27.6 ± 1.34 s (n = 232) to start clicking with only the RV present and 26.2 ± 1.50 s (n = 160) with WWPs.

Data Set 3: Comparison between residents and transients

Resident and transient whales responded differently to presence of WWPs, though the differences were not statistically significant at the specified level. Resident whales decreased the time to first click in the presence of WWPs (Table 21). In contrast, transients increased time to first click in the presence of WWPs. A Mann-Whitney U test resulted in a p-value barely above the 0.05 alpha value. It is worth stressing the difference in reaction here: residents displayed only a small difference when WWPs were present. Transients, on the other hand, increased the time to first click by approximately 20 s in the presence of WWPs.

TABLE 19. AIC ANALYSIS OF TIME TO FIRST CLICK.
See Table 5 for symbol explanations.

DATA SET	FACTORS	RSS	n	K	Δ_I	ω_I
Data Set 1						
	Year×Season×WWP	211.54	596	7	0	0.99
	Year×Season	220.65	596	4	19.13	≤ 0.00
	Year+Season+ WWP	211.54	596	4	29.93	≤ 0.00
	Year+Season	226.67	596	3	33.18	≤ 0.00
Data Set 2						
	Year×Season×ID× WWP (2-way)	62.98	392	11	0	1.00
	Year×Season×ID (2-way)	69.08	392	7	28.24	≤ 0.00
	Year+Season+ID	89.54	392	4	123.93	≤ 0.00
	Year+Season+ID+WWP	89.37	392	5	125.19	≤ 0.00

TABLE 20. SUMMARY OF RESULTS OF GLM ANALYSES ON TIME TO FIRST CLICK.
Response variables were transformed using the natural logarithm in analysis of both data sets.
Significant p-values are marked in bold.
See Table 8 for symbol explanations.

DATA SET	FACTORS	d.f.	F-RATIO	p-VALUE	PV	f
Data Set 1						
	Year	3	6.8	**≤ 0.001**	3.40	0.17
	Season	3	4.24	**0.005**	2.15	0.13
	Year×Season	1	15.04	**≤ 0.001**	2.53	0.15
	WWP	1	4.11	**0.04**	0.71	0.07
	Year×WWP	3	2.37	0.07	1.21	0.08
	Season×WWP	3	2.18	0.09	1.12	0.08
	Year×Season×WWP	1	11.79	**≤ 0.001**	2.00	0.14
Data Set 2						
	Year	3	1.17	0.32	1.51	0.04
	Season	3	0.35	0.79	0.45	0.07
	Year×Season	1	0.27	0.61	0.12	0.04
	ID	68	1.94	**≤ 0.001**	36.55	0.40
	Year×ID	42	1.17	0.24	17.63	0.13
	Season×ID	10	0.72	0.71	3.01	0.09
	WWP	1	0.94	0.33	0.41	0.01
	Year×WWP	3	0.73	0.54	0.95	0.05
	Season×WWP	3	0.76	0.52	0.98	0.04
	ID×WWP	28	0.64	0.92	7.26	0.16

TABLE 21. SUMMARY OF CHANGE IN TIME (SECONDS, + S.E.) TO FIRST CLICK IN RESPONSE TO THE PRESENCE OF WWPS USING DATA SET 3, COMPARING RESIDENTS AND TRANSIENTS.
Tests were Mann-Whitney U tests without ties.
See Table 8 for symbol explanations.

DATA SET	RV	RV+WWP	p-VALUE
Data Set 3: Residents (n = 375)	26.9 ± 1.39	25.1 ± 1.43	0.84
Data Set 3: Transients (n = 17)	39.5 ± 3.80	59.4 ± 11.18	0.07

3.4 THE IMPACT OF THE RESEARCH VESSEL ON SPERM WHALES

The impact of the research vessel can only be assessed by comparing observations of unaccompanied whales from shore with boat-based observations.

Data available for analysis

In order to keep both data sets comparable, data from the same time frame were used. Therefore, boat-based observations were limited to 2000–2001. From shore, we recorded 244 encounters without any WWP in the vicinity of the observed whales. During the same time frame these land-sightings were made (2000–2001), we also logged 263 RV-based encounters without any other WWPs close by.

Model selection: which models best fit the data?

For the analysis of blow mean and median the additive model including all three factors (year, season and RV presence) was required. Coefficient of variation of blow mean was best modelled by year and season without interaction (Table 22).

TABLE 22. AIC ANALYSIS OF BLOW INTERVAL CHARACTERISTICS OF ENCOUNTER WITHOUT WWP AND WITH THE RV.
See Table 5 for symbol explanations.

DATA SET	FACTORS	RSS	n	K	Δ_I	ω_I
Mean blow interval						
	Year+Season+RV	24.18	507	4	0	0.81
	Season×WWP×RV	24.03	507	7	2.85	0.19
	Year+Season	24.94	507	3	13.69	≤ 0.00
CV of blow mean						
	Year+Season	85.13	506	3	0	0.51
	Year+Season+RV	84.87	506	4	0.45	0.41
	Year×Season×RV	84.40	506	7	3.64	0.08
Blow median						
	Year+Season+WWP	20.68	507	4	0	0.85
	Year×Season×WWP	20.58	507	7	3.54	0.14
	Year+Season	21.23	507	3	11.31	≤ 0.00

GLM analysis: which factors are most important?

Both blow mean and median were influenced by the presence of the RV, although differences were small. When unaccompanied, whales exhibited a mean blow interval of 16.9 ± 0.24 s (n = 244) and a median of 16.0 s (95% C.I. = 15.60–16.38 s; n = 244). When the RV was with whales, these changed to 16.1 ± 0.39 s (n = 263) and 15.2 s (95% C.I. = 14.72–15.53 s; n = 263), respectively. Percentages of explained variance and effect sizes are small (Table 23).

TABLE 23. SUMMARY OF RESULTS OF GLM ANALYSES ON BLOW INTERVAL CHARACTERISTICS OF ENCOUNTERS WITHOUT ANY WWPS (COLLECTED FROM SHORE) AND WITH THE RV. RESPONSE VARIABLES WERE TRANSFORMED USING THE NATURAL LOGARITHM.
See Table 8 for symbol explanations.

RESPONSE VARIABLE	FACTORS	d.f.	F-RATIO	p-VALUE	PV	f
Ln(mean)						
	Year	1	13.06	**≤ 0.00**	2.54	0.17
	Season	2	9.72	**≤ 0.00**	3.73	0.21
	RV	1	15.84	**≤ 0.00**	3.06	0.19
Ln(CV)						
	Year	1	6.69	**0.01**	1.32	0.12
	Season	2	3.24	**0.03**	1.27	0.11
Ln(median)						
	Year	1	13.31	**≤ 0.00**	2.58	0.18
	Season	2	10.47	**≤ 0.00**	4.00	0.22
	RV	1	15.05	**≤ 0.00**	2.91	0.19

3.5 THE IMPACT OF WHALE WATCHING BOATS ON SPERM WHALES

3.5.1 Ventilation patterns

Model selection: which model best fits the data?

Data Set 1

AIC analysis of mean and median required the inclusion of year, season and WWboat presence as well as interactions (up to 2-way). CV and number of blows were sufficiently modelled by year and season (Table 24).

Data Set 2

The full model was required without exception (Table 25).

Data Set 4

To model data collected from shore, AIC analysis recommended inclusion of all factors but no interaction terms (Table 26).

GLM analysis: which factors are most important?

None of the analyses showed any significant effect of the presence of the additional WWboats (Table 27). As in previous analyses of this data set, year and season dominated.

TABLE 24. AIC ANALYSIS OF BLOW INTERVAL CHARACTERISTICS OF ENCOUNTERS WITH THE RV AND WITH WWBOATS.
See Table 5 for symbol explanations.

RESPONSE VARIABLE	FACTORS	RSS	n	K	Δ_I	ω_I
Mean blow interval						
	Year×Season×WWboats	54.02	977	8	0	0.62
	Year×Season	54.52	977	4	1.00	0.38
	Year+Season	55.17	977	3	10.58	≤ 0.00
	Year+Season+WWboats	55.17	977	4	12.58	≤ 0.00
Blow median						
	Year×Season×WWboats	51.94	973	8	0	0.93
	Year×Season	52.65	973	4	5.21	0.07
	Year+Season	53.29	973	3	14.97	≤ 0.00
	Year+Season+WWboats	53.22	973	4	15.69	≤ 0.00
CV of blow mean						
	Year+Season	161.11	976	3	0	0.48
	Year+Season+WWboats	160.92	976	4	0.85	0.32
	Year×Season	161.11	976	4	2.00	0.18
	Year×Season×WWboats	160.47	976	8	6.12	0.02
Mean number of blows						
	Year×Season	78.76	435	8	0	0.81
	Year×Season×WWboats	77.40	435	4	3.28	0.16
	Year+Season+WWboats	80.66	435	4	6.97	0.003
	Year+Season	81.28	435	3	10.63	≤ 0.00

TABLE 25. AIC ANALYSIS OF BLOW INTERVAL CHARACTERISTICS USING DATA SET 2.
See Table 5 for symbol explanations.

RESPONSE VARIABLE	FACTORS	RSS	n	K	Δ_I	ω_I
Mean blow interval						
	Year×Season×ID×WWboats (2-way)	8.00	554	11	0	1.00
	Year×Season×ID (2-way, no Year×Season)	8.54	554	7	28.19	≤ 0.00
	Year+Season+ID	11.13	554	4	168.93	≤ 0.00
	Year+Season+ID+WWboats	11.13	554	5	170.93	≤ 0.00
CV of blow mean						
	Year×Season×ID×WWboats (2-way)	50.00	553	11	0	1.00
	Year×Season×ID (2-way, no Year×Season)	53.62	553	7	30.65	≤ 0.00
	Year+Season+ID+WWboats	63.53	553	5	120.44	≤ 0.00
	Year+Season+ID	63.89	553	4	121.56	≤ 0.00
Blow median						
	Year×Season×ID×WWboats (2-way)	11.18	552	11	0	1.00
	Year×Season×ID (2-way)	11.88	552	7	25.52	≤ 0.00
	Year+Season+ID	14.90	552	4	144.55	≤ 0.00
	Year+Season+ID+WWboats	14.86	552	5	145.07	≤ 0.00
Mean number of blows						
	Year×Season×ID×WWboats (2-way)	6529.84	267	11	0	1
	Year×Season×ID (2-way)	8256.76	267	7	54.65	≤ 0.00
	Year+Season+ID	13492.0	267	4	179.77	≤ 0.00
	Year+Season+ID+WWboats	13490.0	267	5	181.74	≤ 0.00

TABLE 26. AIC ANALYSIS OF BLOW INTERVAL CHARACTERISTICS USING DATA SET 4.
See Table 5 for symbol explanations.

RESPONSE VARIABLE	FACTORS	RSS	n	K	Δ_I	ω_I
Mean blow interval						
	Year+Season+WWboats	14.27	350	4	0	0.64
	Year+Season	14.44	350	3	2.14	0.22
	Year×Season×WWboats	14.15	350	7	3.04	0.14
CV of blow mean						
	Year+Season+WWboats	63.91	349	4	0	0.79
	Year×Season×WWboats	63.40	349	7	3.20	0.16
	Year+Season	65.31	349	3	5.56	0.05
Blow median						
	Year+Season+WWboats	14.47	350	4	0	0.48
	Year+Season	14.57	350	3	0.41	0.39
	Year×Season×WWboats	14.33	350	7	2.60	0.13

TABLE 27. SUMMARY OF RESULTS OF GLM ANALYSES ON BLOW INTERVAL CHARACTERISTICS USING DATA SET 1.
See Table 8 for symbol explanations.

RESPONSE VARIABLE	FACTORS	d.f.	F-RATIO	p-VALUE	PV	f
Ln(mean)						
	Year	3	8.43	**≤ 0.001**	2.56	0.24
	Season	3	4.13	**≤ 0.001**	1.27	0.15
	Year×Season	1	8.51	**≤ 0.001**	0.88	0.14
	WWboats	1	≤ 0.001	0.98	< 0.00	0.05
	Year×WWboats	3	0.36	0.78	0.11	0.07
	Season×WWboats	3	0.36	0.79	0.11	0.07
	Year×Season×WWboats	1	0.12	0.73	0.01	0.05
Ln(CV)						
	Year	3	14.06	**≤ 0.001**	4.20	0.32
	Season	3	7.43	**≤ 0.001**	2.24	0.22
Ln(median)						
	Year	3	7.93	**≤ 0.001**	2.43	0.23
	Season	3	2.79	**≤ 0.001**	0.87	0.16
	Year×Season	1	8.14	**≤ 0.001**	0.84	0.13
	WWboats	1	1.66	0.20	0.17	0.04
	Year×WWboats	3	0.92	0.43	0.29	0.02
	Season×WWboats	3	1.36	0.25	0.43	0.05
	Year×Season×WWboats	1	0.04	0.85	0.004	0.05
Number of blows						
	Year	2	3.78	**0.02**	1.74	0.12
	Season	3	6.75	**≤ 0.001**	4.52	0.21
	Year×Season	1	14.82	**≤ 0.001**	3.35	0.19

Data Set 2

As before, individual differences were the most prominent factors in the analyses of blow interval characteristics (Table 28).

TABLE 28. SUMMARY OF RESULTS OF GLM ANALYSES ON BLOW INTERVAL CHARACTERISTICS USING DATA SET 2.
See Table 8 for symbol explanations.

RESPONSE VARIABLE	FACTORS	d.f.	F-RATIO	p-VALUE	PV	f
Ln(mean)						
	Year	3	0.17	0.92	0.15	0.08
	Season	3	0.49	0.69	0.42	0.06
	Year×Season	1	0.03	0.87	0.08	0.05
	ID	91	2.39	**≤ 0.001**	38.67	0.56
	Year×ID	52	1.11	0.29	14.35	0.12
	Season×ID	20	1.28	0.19	6.91	0.12
	WWboats	1	0.51	0.47	0.15	0.03
	Year×WWboats	3	0.28	0.84	0.24	0.07
	Season×WWboats	3	1.43	0.23	1.23	0.06
	ID×WWboats	31	0.62	0.95	5.28	0.17
Ln(CV)						
	Year	3	1.21	0.31	1.04	0.04
	Season	3	1.36	0.25	1.17	0.05
	Year×Season	1	2.52	0.11	0.73	0.06
	ID	91	1.02	0.43	21.25	0.07
	Year×ID	52	0.94	0.60	12.33	0.08
	Season×ID	20	0.81	0.70	4.50	0.08
	WWboats	1	0.001	0.97	0.00	0.04
	Year×WWboats	3	0.15	0.93	0.13	0.07
	Season×WWboats	3	0.71	0.55	0.62	0.04
	ID×WWboats	31	0.69	0.89	5.85	0.13
Ln(median)						
	Year	3	0.74	0.53	0.64	0.04
	Season	3	1.18	0.32	1.02	0.03
	Year×Season	1	0.11	0.74	0.03	0.04
	ID	91	1.76	**≤ 0.001**	31.83	0.35
	Year×ID	52	0.86	0.74	11.53	0.12
	Season×ID	20	1.23	0.23	6.69	0.09
	WWboats	1	0.27	0.60	0.08	0.04
	Year×WWboats	3	0.40	0.76	0.35	0.06
	Season×WWboats	3	2.80	**0.04**	2.39	0.10
	ID×WWboats	31	0.39	0.10	3.4	0.19
Number of blows						
	Year	2	1.33	0.27	2.19	0.05
	Season	3	0.48	0.70	1.20	0.08
	Year×Season	1	0.20	0.65	0.17	0.06
	ID	67	2.29	**≤ 0.001**	56.32	0.57
	Year×ID	34	1.73	**0.02**	33.08	0.31
	Season×ID	12	1.21	0.29	10.88	0.10
	WWboats	1	0.21	0.65	0.18	0.06
	Year×WWboats	2	1.51	0.23	2.48	0.06
	Season×WWboats	3	1.71	0.17	4.13	0.09
	ID×WWboats	22	0.80	0.72	12.88	0.13

Data Set 3: comparison between residents and transients

Ventilation patterns of residents and transients were not impacted by WWboats (Table 29). Interestingly, only transients displayed effect sizes greater than 0.1, while all values for residents were well below this value, indicating that power

TABLE 29. SUMMARY OF RESULTS OF GLM ANALYSES ON BLOW INTERVAL CHARACTERISTICS USING DATA SET 3, COMPARING RESIDENTS AND TRANSIENTS. See Table 8 for symbol explanations.

DATA SET	RESPONSE VARIABLE	d.f.	F-RATIO	p-VALUE	PV	f
Residents						
	Ln(mean)	1	0.43	0.51	0.08	0.03
	Ln(CV)	1	2.99	0.08	0.57	0.06
	Ln(median)	1	1.16	0.28	0.22	0.02
	Number of blows	1	0.06	0.80	0.02	0.06
Transients						
	Ln(mean)	1	1.79	0.19	6.01	0.17
	Ln(CV)	1	0.007	0.94	0.02	0.19
	Ln(median)	1	2.01	0.17	6.70	0.19

was not sufficient to detect changes in transients. We were not able to obtain a complete surfacing with a transient whale and WWboats, therefore we could not compute a GLM for number of blows of transients.

Data Set 4

When compared with encounters without any platform present, WWboats influenced mean blow interval and the CV, which both decreased when WWboats were with the whales (Table 30). Blow means decreased from 16.5 ± 1.01 s (n = 244) to 15.7 ± 1.02 s (n = 106), CV decreased from 23.4 s (95% C.I. = 22.09–24.70 s; n = 243) to 20.1 (95% C.I. = 19.03–22.27 s; n = 106).

TABLE 30. SUMMARY OF RESULTS OF GLM ANALYSES ON BLOW INTERVAL CHARACTERISTICS USING DATA SET 4. See Table 8 for symbol explanations.

DATA SET	RESPONSE VARIABLE	d.f.	F-RATIO	p-VALUE	PV	f
Ln(mean)						
	Year	1	4.61	**0.03**	1.32	0.10
	Season	2	3.43	**0.03**	1.95	0.12
	WWboats	1	4.03	**0.045**	1.16	0.09
Ln(CV)						
	Year	1	3.73	0.05	1.07	0.09
	Season	2	1.68	0.18	0.97	0.06
	WWboats	1	7.57	**0.01**	2.15	0.14
Ln(median)						
	Year	1	3.38	0.07	0.97	0.08
	Season	2	2.43	0.09	1.39	0.09
	WWboats	1	2.41	0.12	0.69	0.06

3.5.2 Surface time

Model selection: which model best fits the data?

Data set 1 required only year and season to describe surface time appropriately, whereas Data Set 2 needed the full model with interactions (Table 31).

TABLE 31. AIC ANALYSIS OF SURFACE TIME.
See Table 5 for symbol explanations.

DATA SET	FACTORS	RSS	n	K	Δ_I	ω_I
Data Set 1						
	Year+Season	7241.47	498	3	0	0.51
	Year+Season+WWboats	7230.56	498	4	1.25	0.28
	Year×Season	7241.13	498	4	1.98	0.19
	Year×Season×WWboats	7191.9	498	8	6.58	0.02
Data Set 2						
	Year×Season×ID×WWboats (2-way)	1092.75	281	11	0	1.00
	Year×Season×ID (2-way)	1312.13	281	7	29.87	≤ 0.001
	Year+Season+ID+WWboats	1674.92	281	5	107.23	≤ 0.001
	Year+Season+ID	1687.43	281	4	113.00	≤ 0.001
	Year×Season	2616.37	281	4	278.82	≤ 0.001
	Year+Season	2599.96	281	3	282.77	≤ 0.001

GLM analysis: which factors are most important?

Data Set 1

None of the factors included was significant (Table 32).

Data Set 2

Surface time was reduced significantly by the presence of WWboats (Table 32). With only the RV in attendance, whales stayed at the surface for 9.3 ± 0.22 min (n = 203). When WWboats were present, this time was reduced to 9.0 ± 0.24 min (n = 78) .

Data Set 3: comparison between residents and transients

Residents did not significantly alter their time at the surface in response to WWboats (RV: 9.3 ± 0.23 min; n = 182; RV+WWboats: 9.0 ± 0.24 min; n = 78) (Table 33). There was no record of a transient with WWboats for which we observed the complete surface period.

TABLE 32. SUMMARY OF RESULTS OF GLM ANALYSES ON SURFACE TIME.
See Table 8 for symbol explanations.

DATA SET	FACTORS	d.f.	F-RATIO	p-VALUE	PV	f
Data Set 1						
	Year	2	0.72	0.49	0.29	0.04
	Season	3	0.52	0.67	0.32	0.06
Data Set 2						
	Year	2	2.97	0.05	4.41	0.12
	Season	3	0.81	0.49	1.85	0.05
	Year×Season	1	0.17	0.69	0.13	0.05
	ID	70	1.27	0.12	40.80	0.26
	Year×ID	34	1.21	0.22	24.18	0.16
	Season×ID	12	0.64	0.80	5.62	0.12
	WWboats	1	3.94	**0.049**	2.96	0.10
	Year×WWboats	2	1.64	0.20	2.48	0.07
	Season×WWboats	3	2.94	**0.04**	6.40	0.14
	ID×WWboats	23	0.78	0.76	11.93	0.14

TABLE 33. SUMMARY OF RESULTS OF GLM ANALYSES ON SURFACE TIME USING DATA SET 3, COMPARING RESIDENTS AND TRANSIENTS.
See Table 5 for symbol explanations.

DATA SET	RESPONSE VARIABLE	d.f.	F-RATIO	p-VALUE	PV	f
Residents						
	WWboats	1	0.04	0.84	0.02	0.06

3.5.3 Directional heading

Data Set 1

Whales responded to WWboats by turning significantly more frequently, but the arc of the turns was not significantly greater (RV: 24.2 ± 2.24°; n = 686; RV+WWboats: 30.3 ± 4.00°; n = 257) (Tables 34 and 35).

Data Set 2

The frequency of turning cannot be compared in this data set, but the arc of the turns can. There was no statistical evidence that whales make larger turns in the presence of WWboats (RV: 24.2 ± 2.68°; n = 377; RV+WWboats: 32.5 ± 4.93°; n = 170) (Table 35).

Data Set 3

Since there were no data on heading change in the presence of WWboats for transients, it is not surprising that the analysis of residents reflects the above results (Tables 34 and 35).

TABLE 34. SUMMARY OF ANALYSES OF FREQUENCY OF HEADING CHANGE IN RESPONSE TO THE PRESENCE OF WWBOATS.
Tests were 2×2 G-tests. Numbers in parentheses give column percentages for each data set.

DATA SET	ENCOUNTER	RV	RV+WWBOATS	p-VALUE
Data Set 1				
	< 10°	491 (72)	160 (62)	**< 0.01**
	> 10°	195 (28)	97 (38)	
Data Set 3: Residents				
	< 10°	347 (71)	136 (63)	**0.04**
	> 10°	140 (29)	79 (37)	

TABLE 35. SUMMARY OF AMOUNT OF HEADING CHANGE (+ S.E.), IN RESPONSE TO THE PRESENCE OF WWBOATS.
Tests were Mann-Whitney U tests without ties.

DATA SET	RV	RV+WWBOATS	p-VALUE
Data Set 1 (n = 943)	24.2 ± 2.24°	30.3 ± 4.00°	0.49
Data Set 2 (n = 547)	24.2 ± 2.68°	32.5 ± 4.93°	0.31
Data Set 3: Residents (n = 512)	24.7 ± 2.90°	32.5 ± 4.93°	0.37

3.5.4 Aerial behaviour

Aerial behaviour was more frequent when only the RV was with whales. This was significant for the complete data set (Data Set 1), but not when analysing residents and transients separately (Table 36).

TABLE 36. SUMMARY OF ANALYSES OF FREQUENCY OF AERIAL BEHAVIOUR IN RESPONSE TO THE PRESENCE OF WWBOATS.
Tests were 2×2 G-tests. Numbers in parentheses give column percentages for each data set.

DATA SET	ENCOUNTER	RV	RV+WWBOATS	p-VALUE
Data Set 1				
	No aerial behaviour	954 (88)	382 (94)	0.001
	Aerial behaviour	124 (12)	25 (6)	
Data Set 3: Residents				
	No aerial behaviour	560 (91)	266 (95)	0.06
	Aerial behaviour	54 (9)	15 (5)	
Data Set 3: Transients				
	No aerial behaviour	50 (96)	1 (100)	
	Aerial behaviour	2 (4)	0	

3.5.5 Time to first click

Model selection: which model best fits the data?

Both data sets were best described by full models with interactions (Table 37).

TABLE 37. AIC ANALYSIS OF TIME TO FIRST CLICK.
See Table 5 for symbol explanations.

DATA SET	FACTORS	RSS	n	K	Δ_I	ω_I
Data Set 1						
	Year×Season×WWboats	174.57	499	8	0	0.99
	Year×Season	181.19	499	4	10.57	0.01
	Year+Season+WWboats	186.44	499	4	24.83	≤ 0.001
	Year+Season	188.89	499	3	29.34	≤ 0.001
Data Set 2						
	Year×Season×ID×WWboats (2-way)	47.26	337	11	0	1.00
	Year×Season×ID (2-way)	52.88	337	7	29.87	≤ 0.001
	Year+Season+ID+WWboats	67.32	337	5	107.23	≤ 0.001
	Year+Season+ID	68.89	337	4	113.00	≤ 0.001
	Year×Season	112.68	337	4	278.82	≤ 0.001
	Year+Season	114.69	337	3	282.77	≤ 0.001

GLM analysis: which factors are most important?

Data Set 1

Together with year, season and their interactions, WWboat presence was also a significant factor (Table 38). Whales reduced the time to first click from 31.4 ± 2.27 s (n = 355) in the presence of the RV to 23.2 ± 1.49 s (n = 144) when WWboats were also present.

TABLE 38. SUMMARY OF RESULTS OF GLM ANALYSES ON TIME TO FIRST CLICK. See Table 8 for symbol explanations.

DATA SET	FACTORS	d.f.	F-RATIO	p-VALUE	PV	f
Data Set 1						
	Season	3	3.63	**0.01**	2.21	0.13
	Year	3	5.61	**≤ 0.001**	3.37	0.17
	Year×Season	1	16.48	**≤ 0.001**	3.30	0.18
	WWboats	1	4.09	**0.04**	0.84	0.08
	Season×WWboats	3	2.14	0.09	1.31	0.08
	Year×WWboats	3	1.64	0.18	1.01	0.06
	Season×Year×WWboats	1	8.68	**0.003**	1.77	0.12
Data Set 2						
	Year	3	1.34	0.26	2.09	0.06
	Season	3	0.53	0.67	0.84	0.07
	Year×Season	1	0.29	0.59	0.15	0.05
	ID	61	1.71	**0.003**	35.69	0.36
	Year×ID	39	1.06	0.39	17.97	0.08
	Season×ID	10	0.86	0.58	4.37	0.07
	WWboats	1	0.74	0.39	0.39	0.03
	Year×WWboats	3	1.01	0.39	1.60	0.01
	Season×WWboats	3	1.04	0.38	1.63	0.02
	ID×WWboats	24	0.67	0.88	7.88	0.15

Data Set 2

Individual differences between whales were the most important factor and the only one significant (Table 38). The fact that whales reduced time to first click from 27.6 ± 1.34 s (n = 232) to 21.0 ± 0.88 s (n = 105) when WWboats were present was not statistically significant.

Data Set 3: comparison between residents and transients

Only data for residents are available. These whales showed a significant difference in time to first click depending on the presence of WWboats. With only the RV present, whales began to click after 26.9 ± 1.39 s (n = 220). When WWboats were also present, whales clicked after 21.0 ± 0.88 s (n = 105), (GLM, d.f. = 1, F-ratio = 5.87; p-value = 0.02; PV = 1.79; f = 0.12).

3.6 THE IMPACT OF WHALE WATCHING AIRCRAFT ON SPERM WHALES

3.6.1 Ventilation pattern

Model selection: which model best fits the data?

Data Set 1

Mean blow interval, CV and median were described best by models containing only year and season. By contrast, number of blows required WWaircraft to be considered (Table 39).

TABLE 39. AIC ANALYSIS OF BLOW INTERVAL CHARACTERISTICS OF ENCOUNTERS WITH THE RV AND WITH WWAIRCRAFT.
See Table 5 for symbol explanations.

RESPONSE VARIABLE	FACTORS	RSS	n	K	Δ_I	ω_I
Mean blow interval						
	Year×Season	43.18	792	4	0	0.80
	Year×Season×WWaircraft	42.98	792	8	4.32	0.09
	Year+Season	43.55	792	3	4.76	0.07
	Year+Season+WWaircraft	43.54	792	4	6.58	0.03
Blow median						
	Year×Season	37.95	790	4	0	0.77
	Year+Season	38.24	790	3	4.01	0.10
	Year×Season×WWaircraft	37.77	790	8	4.24	0.09
	Year+Season+WWaircraft	38.24	790	4	5.99	0.04
CV of blow mean						
	Year+Season	128.25	792	3	0	0.55
	Year×Season	128.22	792	4	1.82	0.22
	Year+Season+WWaircraft	128.25	792	4	2.00	0.20
	Year×Season×WWaircraft	127.67	792	8	6.41	0.02
Number of blows						
	Year×Season×WWaircraft	40564.3	368	8	0	0.97
	Year×Season	42318.7	368	4	7.58	0.02
	Year+Season+WWaircraft	42596.6	368	4	9.99	≤ 0.00
	Year+Season	42948.1	368	3	11.01	≤ 0.00

Data Set 2

The full model was required without exception (Table 40).

TABLE 40. AIC ANALYSIS OF BLOW INTERVAL CHARACTERISTICS USING DATA SET 2.
See Table 5 for symbol explanations.

RESPONSE VARIABLE	FACTORS	RSS	n	K	Δ_I	ω_I
Mean blow interval						
	Year×Season×ID×WWaircraft (2-way)	5.10	440	11	0	1.00
	Year×Season×ID (2-way, no Year×Season)	5.53	440	7	27.62	≤ 0.00
	Year+Season+ID	7.38	440	4	148.59	≤ 0.00
	Year+Season+ID+WWaircraft	7.38	440	5	150.59	≤ 0.00
CV of blow mean						
	Year×Season×ID×WWaircraft (2-way)	34.84	440	11	0	1.00
	Year×Season×ID (2-way, no Year×Season)	38.35	440	7	34.23	≤ 0.00
	Year+Season+ID+WWaircraft	45.76	440	5	107.96	≤ 0.00
	Year+Season+ID	46.12	440	4	109.41	≤ 0.00
Blow median						
	Year×Season×ID×WWaircraft (2-way)	4.97	439	11	0	1.00
	Year×Season×ID (2-way)	5.41	439	7	29.24	≤ 0.00
	Year+Season+ID	7.34	439	4	157.17	≤ 0.00
	Year+Season+ID+WWaircraft	7.34	439	5	159.17	≤ 0.00
Mean number of blows						
	Year×Season×ID×WWaircraft (2-way)	5410.3	223	11	0	1
	Year×Season×ID (2-way)	6086.9	223	7	18.28	≤ 0.00
	Year+Season+ID+WWaircraft	10080.0	223	5	126.76	≤ 0.00
	Year+Season+ID	10287.1	223	4	129.30	≤ 0.00

Data Set 4

To model data collected from shore, AIC analysis recommended inclusion of aircraft presence for median and CV, but not for the mean (Table 41).

TABLE 41. AIC ANALYSIS OF BLOW INTERVAL CHARACTERISTICS USING DATA SET 4. See Table 5 for symbol explanations.

RESPONSE VARIABLE	FACTORS	RSS	n	K	Δ_I	ω_I
Mean blow interval						
	Season	9.65	273	2	0	0.41
	Season×WWaircraft	9.52	273	4	0.30	0.36
	Season+WWaircraft	9.62	273	3	1.15	0.23
CV of blow mean						
	Season×WWaircraft	49.35	272	4	0	0.86
	Season	50.93	272	2	4.57	0.09
	Season+WWaircraft	50.72	272	3	5.45	0.06
Blow median						
	Season×WWaircraft	9.47	273	4	0	0.48
	Season	9.64	273	2	0.86	0.31
	Season+WWaircraft	9.60	273	3	1.72	0.20

GLM analysis: which factors are most important?

Data Set 1

While year and season dominated in the analyses of mean, CV and median, WWaircraft presence did influence the number of blows per surfacing (Table 42). Whales with only the RV close by blew 30.2 ± 0.61 (n = 326) times, while those with WWaircraft blew 33.5 ± 1.74 (n = 42) times.

TABLE 42. SUMMARY OF RESULTS OF GLM ANALYSES ON BLOW INTERVAL CHARACTERISTICS USING DATA SET 1.
See Table 8 for symbol explanations.

RESPONSE VARIABLE	FACTORS	d.f.	F-RATIO	p-VALUE	PV	f
Ln(mean)						
	Year	3	7.27	**≤ 0.001**	9.36	0.31
	Season	3	4.83	**0.003**	1.81	0.12
	Year×Season	1	6.73	**0.009**	0.85	0.09
Ln(CV)						
	Year	3	12.75	**≤ 0.001**	4.65	0.21
	Season	3	4.93	**0.002**	1.85	0.12
Ln(median)						
	Year	3	8.16	**≤ 0.001**	3.03	0.17
	Season	3	4.66	**0.003**	1.76	0.12
	Year×Season	1	5.96	**0.02**	0.76	0.08
Number of blows						
	Year	2	0.51	0.60	0.29	0.05
	Season	3	2.00	0.11	1.66	0.09
	Year×Season	1	1.25	0.27	0.35	0.03
	WWaircraft	1	7.06	**0.008**	1.96	0.13
	Year×WWaircraft	2	1.29	0.28	0.72	0.04
	Season×WWaircraft	3	2.18	0.09	1.81	0.10
	Year×Season×WWaircraft	1	9.45	**0.002**	2.60	0.15

Data Set 2

As before, individual differences were the most prominent factors in the analyses of blow interval characteristics, and WWaircraft presence did not have a discernible impact (Table 43).

TABLE 43. SUMMARY OF RESULTS OF GLM ANALYSES ON BLOW INTERVAL CHARACTERISTICS USING DATA SET 2.
See Table 8 for symbol explanations.

RESPONSE VARIABLE	FACTORS	d.f.	F-RATIO	p-VALUE	PV	f
Ln(mean)						
	Year	3	0.87	0.46	1.11	0.03
	Season	3	0.88	0.45	1.13	0.03
	Year×Season	1	1.51	0.22	0.65	0.03
	ID	97	1.92	**≤ 0.001**	44.53	0.45
	Year×ID	50	1.00	0.48	17.75	0.01
	Season×ID	15	1.15	0.32	6.90	0.07
	WWplanes	1	0.43	0.52	0.19	0.04
	Year×WWaircraft	3	1.23	0.30	1.56	0.04
	Season×WWaircraft	3	1.64	0.18	2.08	0.07
	ID×WWaircraft	31	0.44	1.00	5.55	0.20
Ln(CV)						
	Year	3	0.35	0.79	0.45	0.07
	Season	3	0.17	0.92	0.22	0.08
	Year×Season	1	0.67	0.41	0.29	0.03
	ID	97	0.92	0.67	27.86	0.13
	Year×ID	50	0.63	0.97	11.94	0.21
	Season×ID	15	0.47	0.95	2.95	0.14
	WWaircraft	1	<0.000	0.99	<0.01	0.05
	Year×WWaircraft	3	0.03	0.99	0.04	0.08
	Season×WWaircraft	3	0.16	0.92	0.21	0.08
	ID×WWaircraft	31	0.58	0.96	7.24	0.17
Ln(median)						
	Year	3	1.13	0.34	1.45	0.03
	Season	3	1.27	0.29	1.62	0.04
	Year×Season	1	2.27	0.13	0.97	0.05
	ID	97	1.99	**≤ 0.001**	45.49	0.47
	Year×ID	50	1.08	0.35	18.95	0.10
	Season×ID	15	1.40	0.15	8.33	0.12
	WWaircraft	1	1.00	0.32	0.43	<0.01
	Year×WWaircraft	3	1.50	0.22	1.91	0.06
	Season×WWaircraft	3	1.78	0.15	2.26	0.07
	ID×WWaircraft	31	0.46	1.00	5.79	0.20
Number of blows						
	Year	2	0.88	0.42	1.98	0.03
	Season	3	0.57	0.64	1.92	0.08
	Year×Season	1	0.02	0.89	0.03	0.07
	ID	71	2.14	**≤ 0.001**	63.59	0.60
	Year×ID	27	1.23	0.24	27.63	0.17
	Season×ID	9	1.05	0.41	9.78	0.04
	WWaircraft	1	2.14	0.15	2.41	0.07
	Year×WWaircraft	2	0.92	0.40	2.06	0.03
	Season×WWaircraft	3	0.89	0.45	2.97	0.04
	ID×WWaircraft	16	0.58	0.89	9.64	0.17

Data Set 3: comparison between residents and transients

Only the number of blows per surfacing of residents and transients was impacted by WWaircraft (Table 44). Residents increased the mean number of blows from 31.6 ± 0.69 (n = 172) to 36.5 ± 1.62 (n = 31). By contrast, transients reduced the mean number of blows in presence of WWaircraft from 37.3 ± 2.36 (n = 18) to 23.0 (n = 2). Again, transients displayed generally larger effect sizes than residents (Table 44).

TABLE 44. SUMMARY OF RESULTS OF GLM ANALYSES ON BLOW INTERVAL CHARACTERISTICS USING DATA SET 3, COMPARING RESIDENTS AND TRANSIENTS. See Table 8 for symbol explanations.

DATA SET	RESPONSE VARIABLE	d.f.	F-RATIO	p-VALUE	PV	f
Residents						
	Ln(mean)	1	0.08	0.77	0.02	0.05
	Ln(CV)	1	0.48	0.49	0.12	0.04
	Ln(median)	1	0.06	0.81	0.01	0.05
	Number of blows	1	8.71	**0.004**	4.15	0.20
Transients						
	Ln(mean)	1	0.08	0.78	0.22	0.16
	Ln(CV)	1	1.08	0.31	2.91	0.05
	Ln(median)	1	0.04	0.85	0.10	0.16
	Number of blows	1	3.05	0.10	14.48	0.33

Data Set 4

The presence of WWaircraft had only a very small effect on the variables measured from shore (Table 45).

TABLE 45. SUMMARY OF RESULTS OF GLM ANALYSES ON BLOW INTERVAL CHARACTERISTICS USING DATA SET 4. See Table 8 for symbol explanations.

RESPONSE VARIABLE	FACTORS	d.f.	F-RATIO	p-VALUE	PV	f
Ln(mean)						
	Season	3	2.55	0.06	2.77	0.13
Ln(CV)						
	Season	3	0.89	0.45	0.44	0.08
	WWaircraft	1	0.004	0.95	0.92	0.07
	Season×WWaircraft	3	2.44	0.07	1.41	0.05
Ln(median)						
	Season	3	0.39	0.76	1.00	0.04
	WWaircraft	1	2.46	0.12	0.001	0.06
	Season×WWaircraft	3	1.26	0.29	2.70	0.13

3.6.2 Surface time

Model selection: which model best fits the data?

Data Set 1 required only year and season to describe surface time appropriately, whereas Data Set 2 needed the full model with interactions (Table 46).

TABLE 46. AIC ANALYSIS OF SURFACE TIME.
See Table 5 for symbol explanations.

DATA SET	FACTORS	RSS	n	K	Δ_I	ω_I
Data Set 1						
	Year+Season	6484.53	427	3	0	0.46
	Year+Season+WWaircraft	6466.65	427	4	0.82	0.31
	Year×Season	6479.83	427	4	1.69	0.20
	Year×Season×WWaircraft	6409.43	427	8	9.03	0.04
Data Set 2						
	Year×Season×ID×WWaircraft (2-way)	8.02	236	11	0	1.00
	Year×Season×ID (2-way)	8.89	236	7	16.31	≤ 0.001
	Year+Season+ID	12.93	236	4	98.72	≤ 0.001
	Year+Season+ID+WWaircraft	12.85	236	5	99.25	≤ 0.001
	Year+Season	26.64	236	4	267.31	≤ 0.001
	Year×Season	26.63	236	3	269.22	≤ 0.001

GLM analysis: which factors are most important?

Data Set 1

None of the factors included was significant (Table 46).

Data Set 2

The only strong influence on surface time is due to individual differences. Surface time was not influenced by the presence of WWaircraft (Table 47).

Data Set 3: Comparison between residents and transients

Transients once again reacted differently to WWaircraft, by reducing their surface time in the presence of aircraft (RV: 9.7 ± 0.74 mim; n = 21; RV+WWaircraft: 7.0 ± 0.77 min; n = 2). However, none of these effects was significant (Table 48).

TABLE 47. SUMMARY OF RESULTS OF GLM ANALYSES ON SURFACE TIME.
See Table 8 for symbol explanations.

DATA SET	FACTORS	d.f.	F-RATIO	p-VALUE	PV	f
Data Set 1						
	Year	2	0.63	0.54	0.30	0.04
	Season	3	0.86	0.46	0.33	0.06
Data Set 2						
	Year	2	2.85	0.06	5.72	0.13
	Season	3	0.44	0.73	1.39	0.09
	Year×Season	1	0.03	0.86	0.03	0.06
	ID	74	1.72	**0.006**	57.56	0.48
	Year×ID	28	1.21	0.25	26.49	0.16
	Season×ID	11	0.88	0.57	9.30	0.08
	WWaircraft	1	0.19	0.67	0.20	0.06
	Year×WWaircraft	2	0.22	0.80	0.47	0.08
	Season×WWaircraft	3	0.37	0.77	1.18	0.09
	ID×WWaircraft	16	0.49	0.95	7.70	0.19

TABLE 48. SUMMARY OF RESULTS OF GLM ANALYSES ON SURFACE TIME USING DATA SET 3, COMPARING RESIDENTS AND TRANSIENTS.
See Table 8 for symbol explanations.

DATA SET	RESPONSE VARIABLE	d.f.	F-RATIO	p-VALUE	PV	f
Residents						
	WWaircraft	1	2.63	0.11	1.23	0.09
Transients						
	WWaircraft	1	0.49	0.49	2.28	0.15

3.6.3 Directional heading

Data Set 1

When the RV was joined by a WWaircraft, the whales responded by turning over a wider arc (RV: 24.2 ± 2.24°; n = 686; RV+WWaircraft: 30.7 ± 7.25°; n = 77). There was no convincing evidence, however, that whales turned more often in the presence of WWaircraft (Tables 49 and 50).

Data Set 2

TABLE 49. SUMMARY OF ANALYSES OF FREQUENCY OF HEADING CHANGE IN RESPONSE TO THE PRESENCE OF WWAIRCRAFT.
Tests were 2×2 G-tests and Fisher's Exact test for analysis of the transients. Numbers in parentheses give column percentages for each data set.

DATA SET	ENCOUNTER	RV	RV+WWAIRCRAFT	p-VALUE
Data Set 1				
	< 10°	491 (72)	47 (61)	0.06
	> 10°	195 (28)	30 (39)	
Data Set 3: Residents				
	< 10°	347 (71)	33 (63)	0.25
	> 10°	140 (29)	19 (37)	
Data Set 3: Transients				
	< 10°	39 (78)	4 (50)	0.10
	> 10°	11 (22)	4 (50)	

TABLE 50. SUMMARY OF AMOUNT OF HEADING CHANGE (+ S.E.) IN RESPONSE TO THE PRESENCE OF WWAIRCRAFT.
Tests were Mann-Whitney U tests without ties.

DATA SET	RV	RV+WWAIRCRAFT	p-VALUE
Data Set 1 (n = 763)	24.2 ± 2.24°	30.7 ± 7.25°	**0.04**
Data Set 2 (n = 435)	24.2 ± 2.68°	31.0 ± 8.87°	**0.01**
Data Set 3: Residents (n = 392)	24.7 ± 2.90°	30.8 ± 10.2°	**0.01**
Data Set 3: Transients (n = 41)	17.3 ± 5.91°	32.5 ± 10.13°	0.19

This data set showed the same tendency as the previous set, with whales turning over a wider arc in the presence of WWaircraft (RV: 24.2 ± 2.68°; n = 377; RV+WWaircraft: 31.0 ± 8.87°; n = 58) (Table 50).

Data Set 3

Neither residents nor transients significantly changed the frequency of heading changes in response to WWaircraft (Table 49). However, residents in Data Set 3 turned over significantly wider arcs in the presence of aircraft. For transients the difference was larger, but possibly not significant because of low sample size (Table 50).

3.6.4 Aerial behaviour

Aerial behaviour was more frequent (though not significantly so) when only the RV was with whales. This was not significant for any of the data sets (Table 51).

TABLE 51. SUMMARY OF ANALYSES OF FREQUENCY OF AERIAL BEHAVIOUR IN RESPONSE TO THE PRESENCE OF WWAIRCRAFT.
Tests were 2×2 G-tests and Fisher's Exact test for resident analysis. Numbers in parenthese give column percentages for each data set.

DATA SET	ENCOUNTER	RV	RV+WWAIRCRAFT	p-VALUE
Data Set 1				
	No aerial behaviour	954 (88)	101 (94)	0.09
	Aerial behaviour	124 (12)	7 (6)	
Data Set 3: Residents				
	No aerial behaviour	560 (91)	58 (94)	0.3
	Aerial behaviour	54 (9)	4 (6)	
Data Set 3: Transients				
	No aerial behaviour	50 (96)	8 (100)	
	Aerial behaviour	2 (4)	0	

3.6.5 Time to first click

Model selection: which model best fits the data?

Both data sets were best described by full models with interactions (Table 52).

GLM analysis: which factors are most important?

Data Set 1

Year, season and their interactions were significant factors (Table 53). Inclusion of aircraft into the model provided only marginal improvement in fit.

Data Set 2

The individual difference between whales was the most important factor and the only significant one (Table 53). The fact that whales increased mean time to first click from 27.6 ± 1.34 s (n = 232) to 34.8 ± 4.28 s (n = 46) when WWaircraft were present was not significant, as this difference was swamped by variation among individual whales.

Data Set 3: comparison between residents and transients

Both residents and transients delayed their time to first click in the presence of WWaircraft, but the difference is non-significant (Table 54). In the case of transients, non-significance is probably a consequence of low sample size. Residents clicked after 26.9 ± 1.39 s (n = 220) while with the RV only. With WWaircraft also present, they clicked after 31.8 ± 4.42 s (n = 41). Transients increased their mean time to first click from 39.5 ± 3.80 s (n = 12) s to 59.4 ± 11.18 s (n = 5).

TABLE 52. AIC ANALYSIS OF TIME TO FIRST CLICK.
See Table 5 for symbol explanations.

DATA SET	FACTORS	RSS	n	K	Δ_I	ω_I
Data Set 1						
	Year×Season×WWboats	166.41	415	8	0	0.99
	Year×Season	173.83	415	4	10.10	0.006
	Year+Season	182.22	415	3	27.67	≤ 0.001
	Year+Season+WWaircraft	182.18	415	4	29.57	≤ 0.001
Data Set 2						
	Year×Season×ID×WWplanes (2-way)	62.98	392	11	0	1.00
	Year×Season×ID (2-way)	69.08	392	7	28.24	≤ 0.001
	Year+Season+ID	89.54	392	4	123.93	≤ 0.001
	Year+Season+ID+WWaircraft	89.37	392	5	125.19	≤ 0.001
	Year×Season	140.03	392	4	299.22	≤ 0.001
	Year+Season	141.78	392	3	302.09	≤ 0.001

TABLE 53. SUMMARY OF RESULTS OF GLM ANALYSES ON TIME TO FIRST CLICK.
See Table 8 for symbol explanations.

DATA SET	FACTORS	d.f.	F-RATIO	p-VALUE	PV	f
Data Set 1						
	Season	3	7.51	**≤ 0.001**	5.33	0.22
	Year	3	9.68	**≤ 0.001**	6.77	0.25
	Year×Season	1	25.18	**≤ 0.001**	5.92	0.24
	WWaircraft	1	0.28	0.60	0.07	0.04
	Season×WWaircraft	3	2.25	0.08	1.66	0.10
	Year×WWaircraft	3	3.32	0.02	2.43	0.13
Data Set 2						
	Year	3	0.13	0.94	0.29	0.10
	Season	3	0.43	0.73	0.95	0.08
	Year×Season	1	0.05	0.83	0.03	0.06
	ID	68	1.63	**0.008**	45.09	0.39
	Year×ID	37	1.11	0.32	23.37	0.12
	Season×ID	7	1.11	0.36	5.42	0.05
	WWaircraft	1	0.54	0.46	0.38	0.04
	Year×WWaircraft	3	0.28	0.84	0.62	0.09
	Season×WWaircraft	1	0.16	0.69	0.12	0.06
	ID×WWaircraft	18	0.69	0.82	8.43	0.14

TABLE 54. SUMMARY OF RESULTS OF GLM ANALYSES ON TIME TO FIRST CLICK DATA SET 3, COMPARING RESIDENTS AND TRANSIENTS.
See Table 8 for symbol explanatons.

DATA SET	RESPONSE VARIABLE	d.f.	F-RATIO	p-VALUE	PV	f
Residents						
	WWaircraft	1	0.49	0.48	0.18	0.04
Transients						
	WWaircraft	1	1.72	0.21	10.29	0.21

3.7 SPATIAL DISTRIBUTION

Figures 8 to 15 (cf. Fig. 1) display annual sightings of sperm whales per square, standardised by the search effort in each square. There is no clear trend; whales did not seem to alter their spatial distribution over the eight years for which data are available. Figures 16 to 19 show the seasonal distribution of sightings per square, again standardised by effort. A clear preference for the deepest parts of the canyon are obvious in autumn and winter (Figs 17 and 18). By contrast, sperm whales disperse more in spring and summer (Figs 19 and 16). This confirms the finding from earlier reports, that sperm whales alter their spatial distribution depending on seasons, which is likely to be in response to changed prey distribution (Jaquet et al. 2000).

Most sightings with WWboats were close to shore and over the northwestern part of the canyon. Whale watch operators have an incentive to reduce travel time, and so tend to target the closest whales available. This area corresponds to the most inshore section covered by the RV (Figs 20 and 21). Sightings with the RV and WWplanes followed a similar pattern, although sightings further offshore were slightly more common (Fig. 22), presumably because of the faster speed and, therefore, greater range of the aircraft. Only a few encounters with both WWboats and WWaircraft present were recorded, all of which, however, were in the canyon area (Fig. 23). The general pattern of inshore distribution of sightings with WWPs is even clearer when sightings were divided into encounters with and without WWPs (Figs 24 and 25). WWPs concentrated their activity on the most northerly and inshore part of the canyon. When comparing this distribution with that of resident and transient animals (Figs 26 and 27, respectively), it is obvious that WWPs only rarely observe transient animals. There is virtually no overlap between the area where most transients were seen and that of highest WWP activity.

3.8 WHAT PROPORTION OF TIME ARE RESIDENT WHALES ACCOMPANIED BY WHALE WATCH BOATS?

Because of the frequently negative reaction of transients to boats, the availability of residents is a potentially limiting factor for whale watching at Kaikoura.

In this study, we usually found whales using our directional hydrophones, which have a range of 3–5 nautical miles. After finding a whale, we would track it acoustically until it surfaced, gather the data we needed, and then use the directional hydrophone to find another whale. Consequently, we typically ranged over a greater area than the WWboats, for which the most efficient practice is to focus on the whales closest to South Bay. The average number of different whales we photographed per day is, then, a reasonable estimate of the number of whales available to the whale watch fleet. Data on the average length of dive cycles are available from an eight year study by Jaquet et al. (2000). Whale Watch™ Kaikoura Ltd operates, in summer, for about 10 hours a day (7:30 start of first tour, approximately 17:30 return of last trip). Dividing this period by the length of dive cycles, and multiplying that by the number of resident individuals, gives the number of surfacings that are potentially available to WWboats (Table 55).

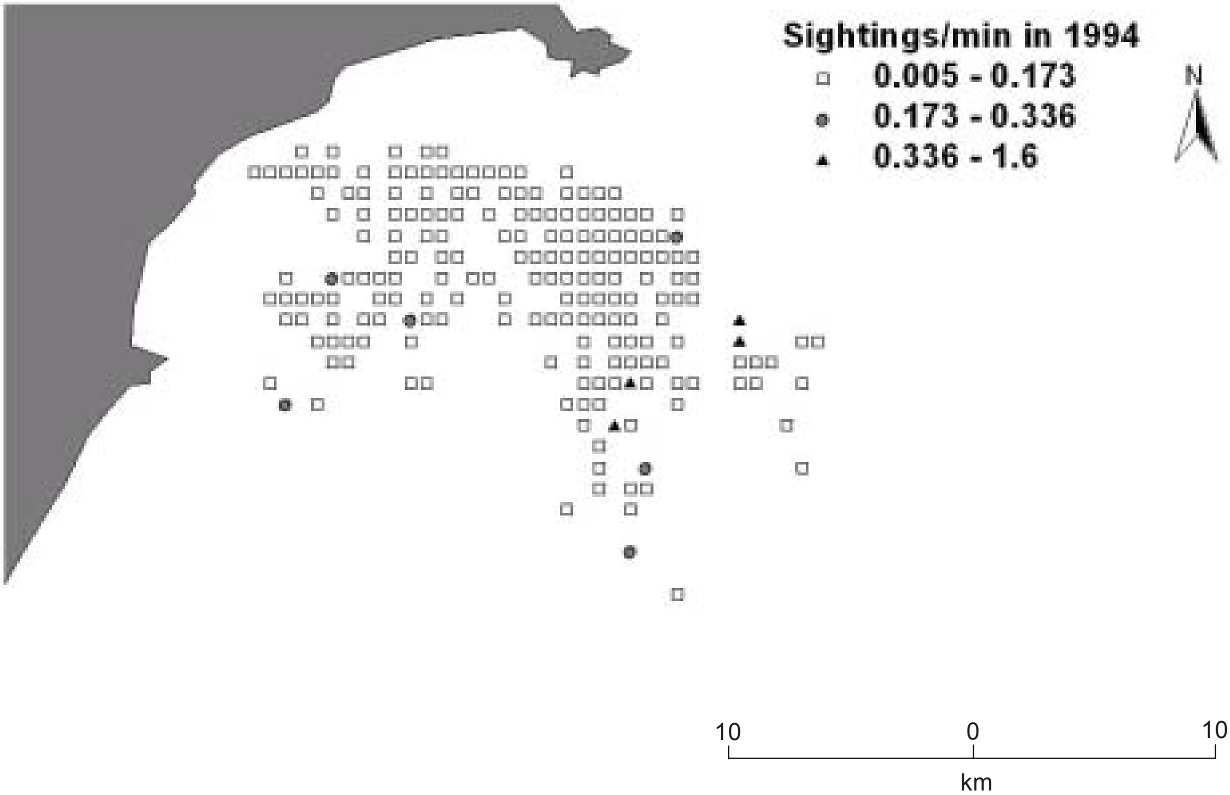


Figure 8. Sighting rates of sperm whales (sightings/min) off Kaikoura in 1994.

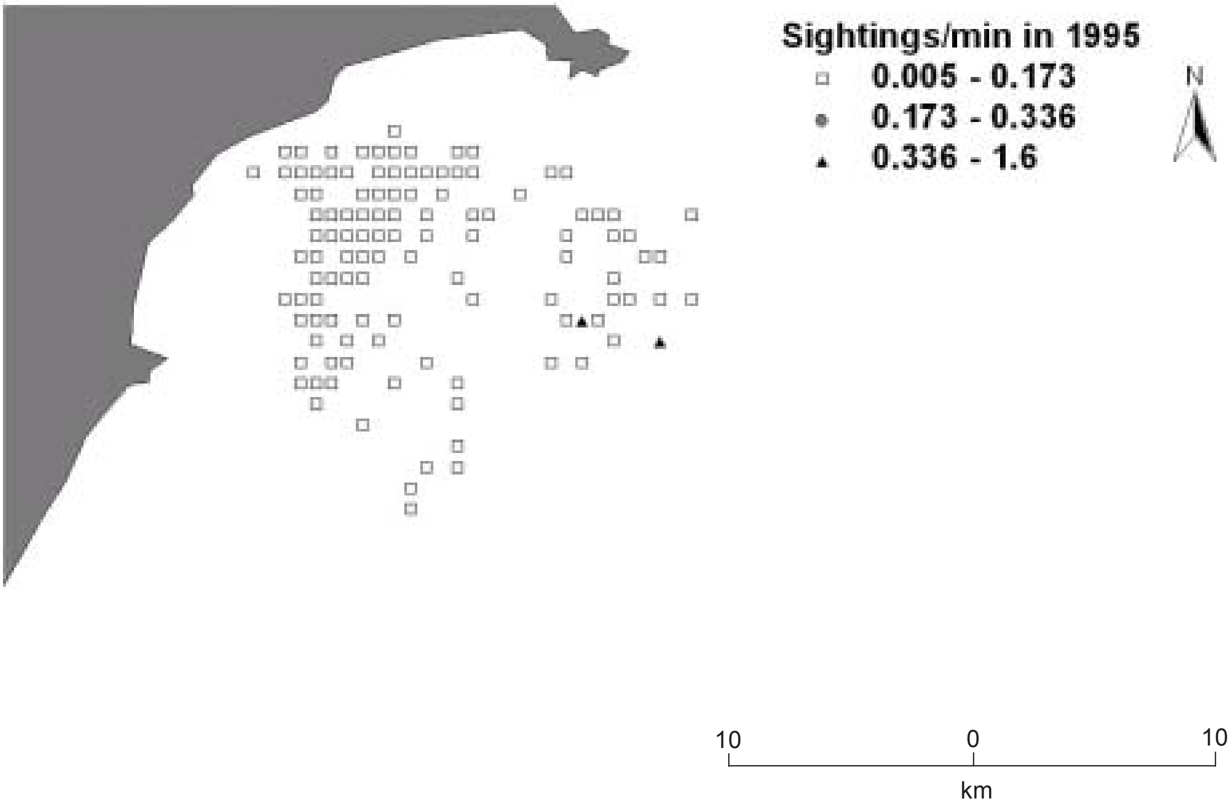


Figure 9. Sighting rates of sperm whales (sightings/min) off Kaikoura in 1995.

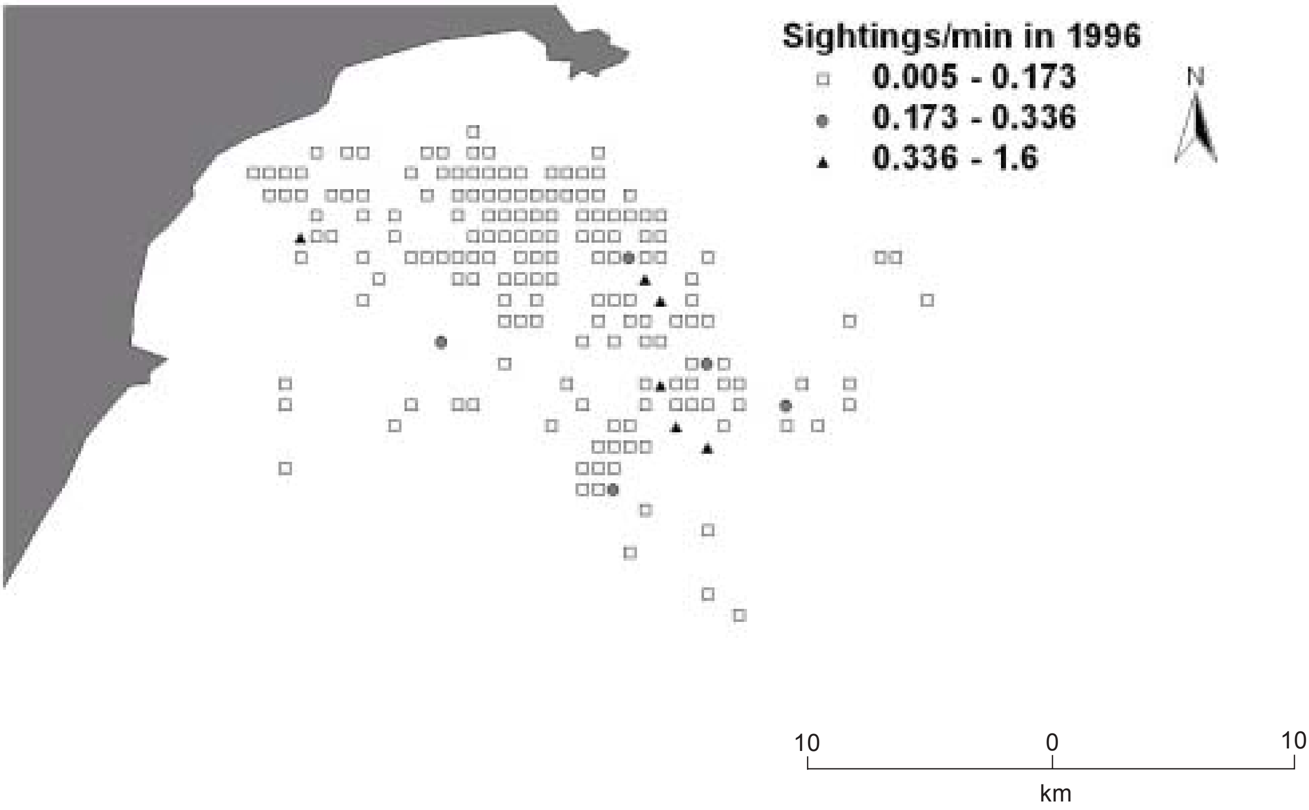


Figure 10. Sighting rates of sperm whales (sightings/min) off Kaikoura in 1996.

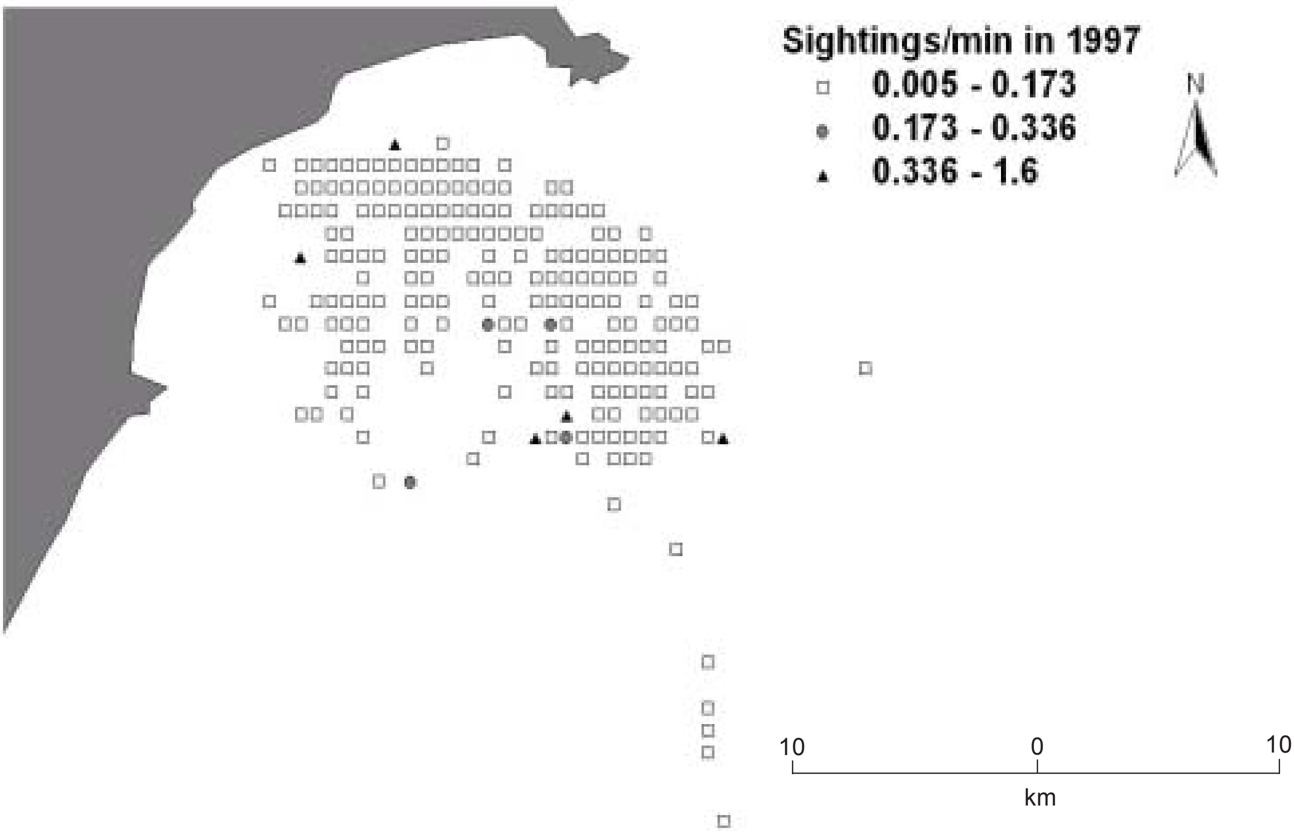


Figure 11. Sighting rates of sperm whales (sightings/min) off Kaikoura in 1997.

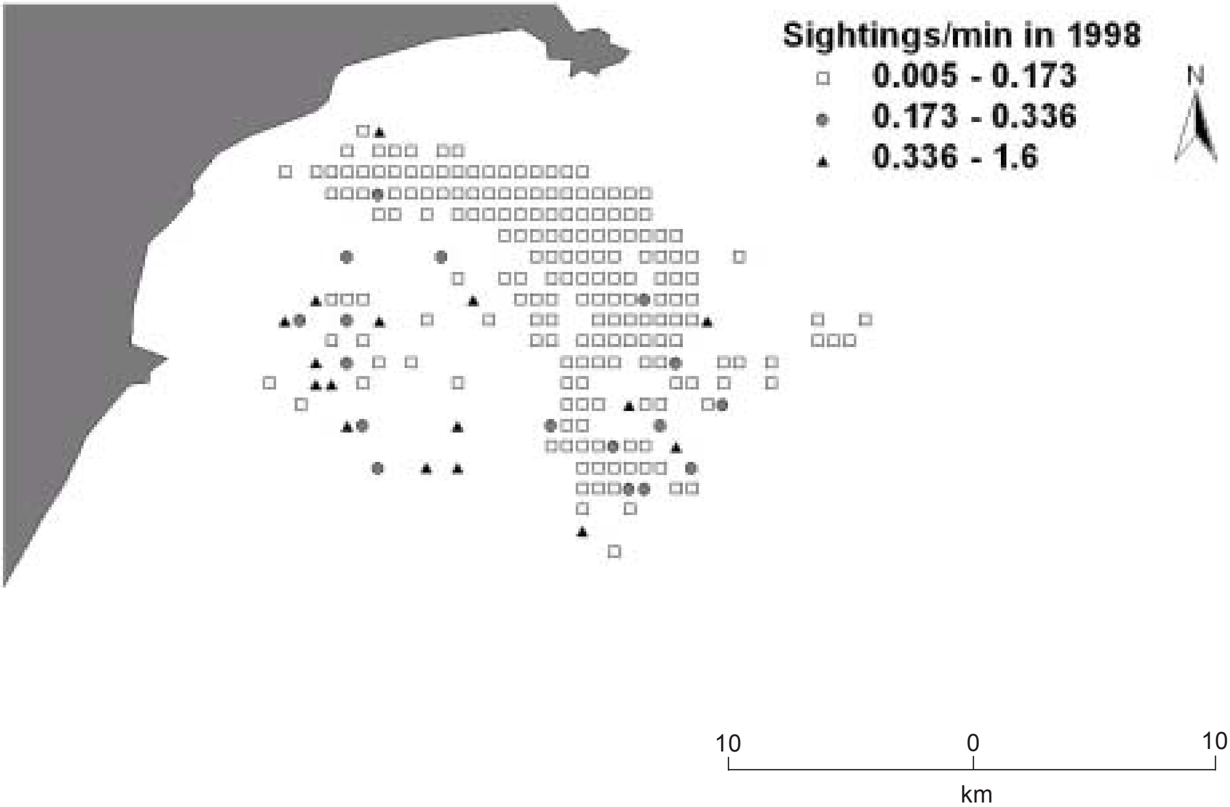


Figure 12. Sighting rates of sperm whales (sightings/min) off Kaikoura in 1998.

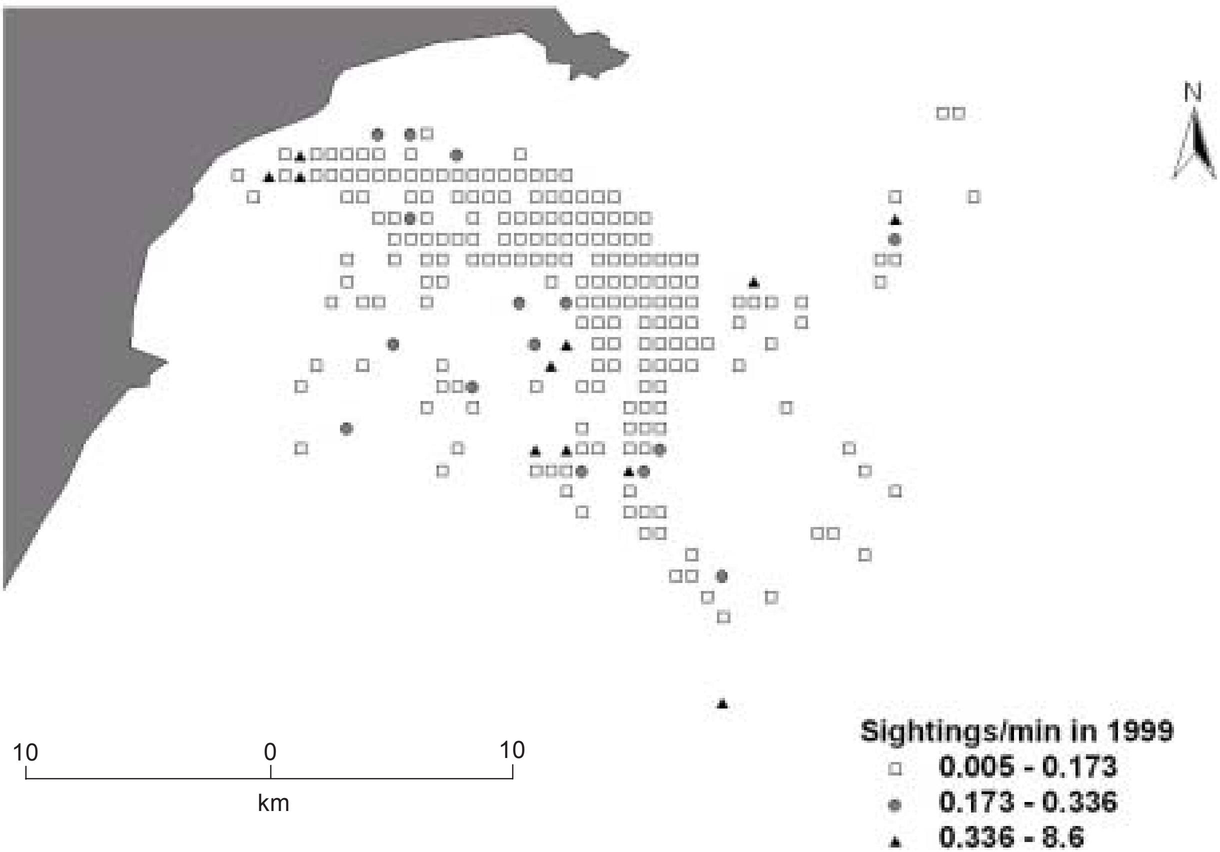


Figure 13. Sighting rates of sperm whales (sightings/min) off Kaikoura in 1999.

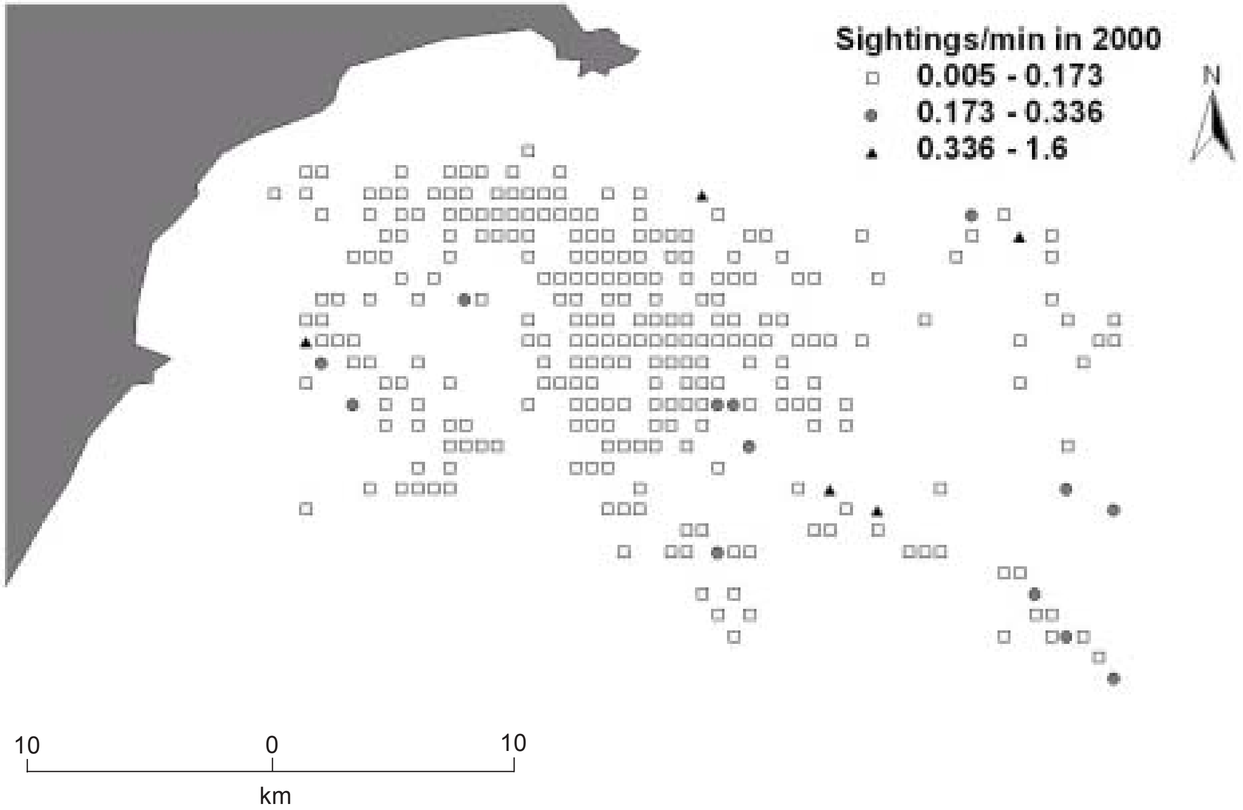


Figure 14. Sighting rates of sperm whales (sightings/min) off Kaikoura in 2000.

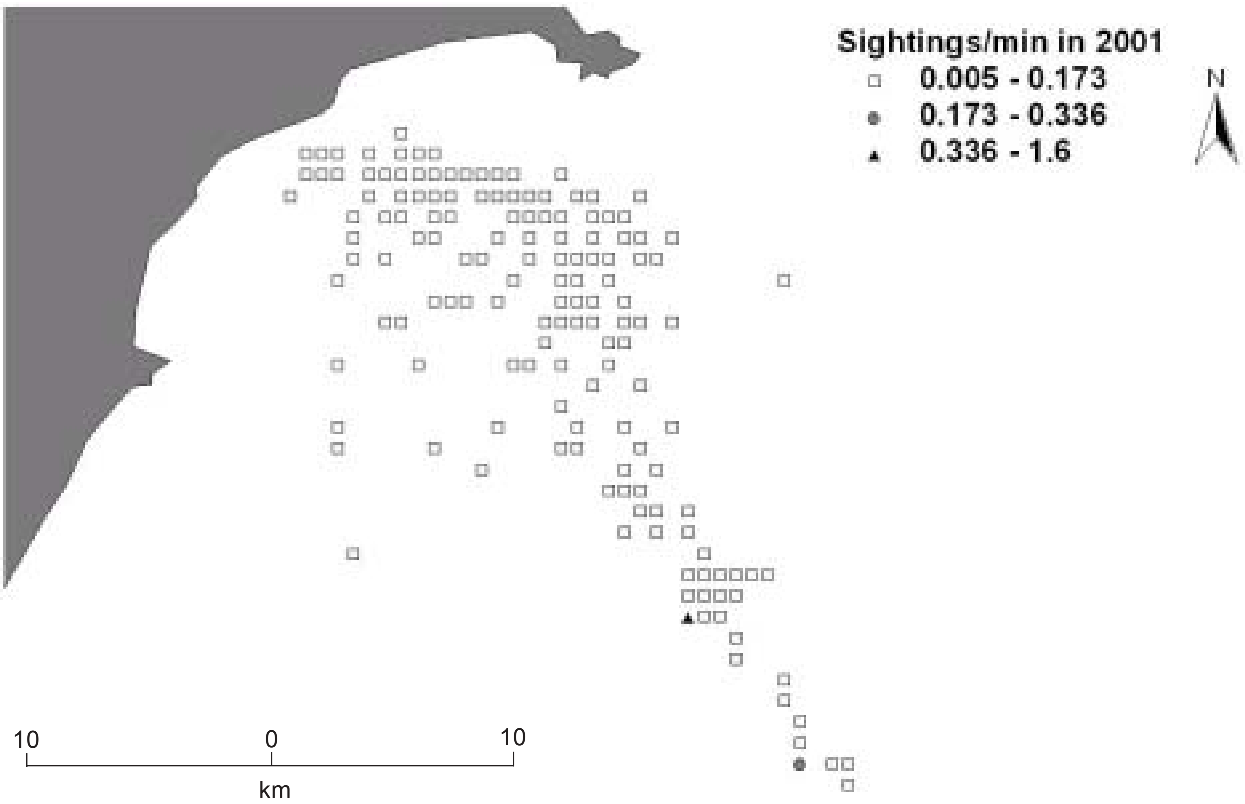


Figure 15. Sighting rates of sperm whales (sightings/min) off Kaikoura in 2001.

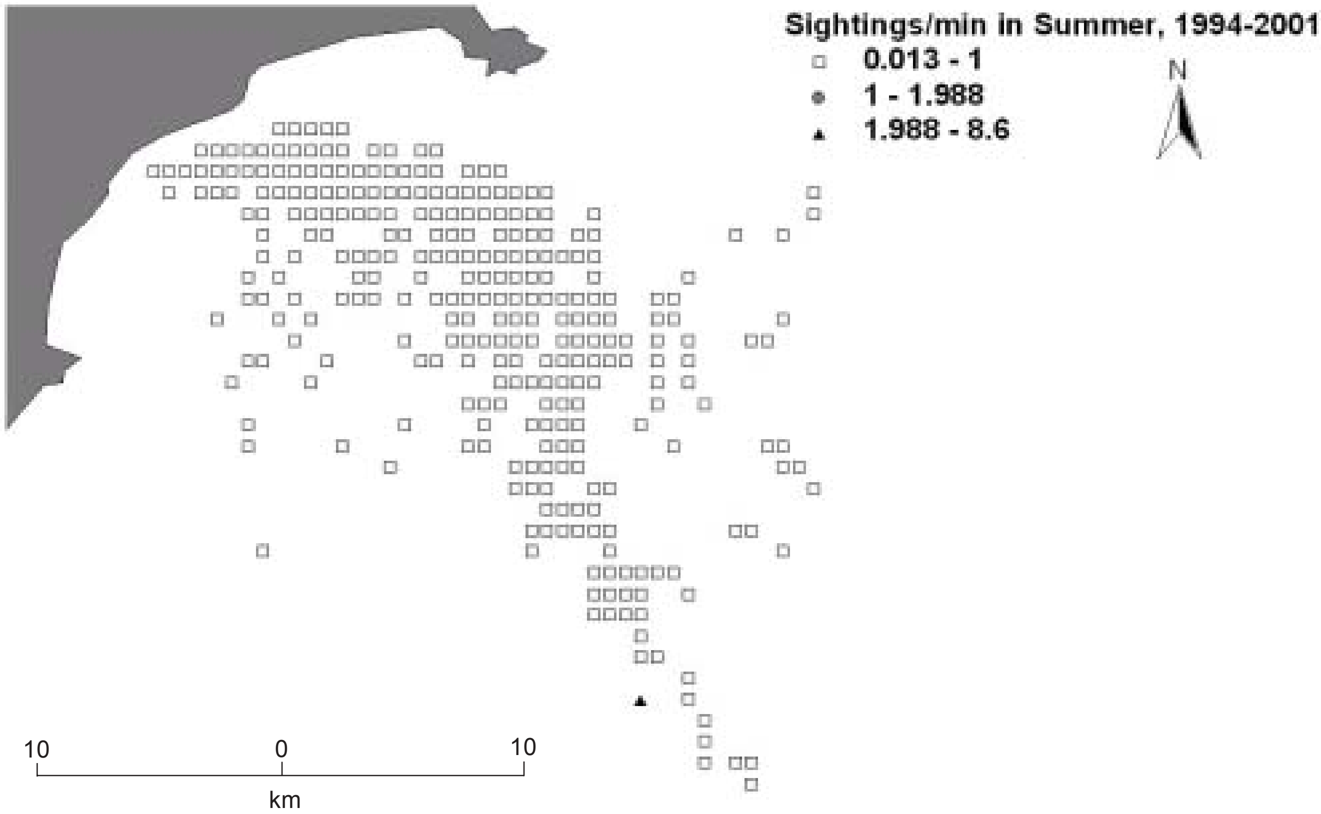


Figure 16. Sighting rates of sperm whales (sightings/min) off Kaikoura in summer, 1994–2001.

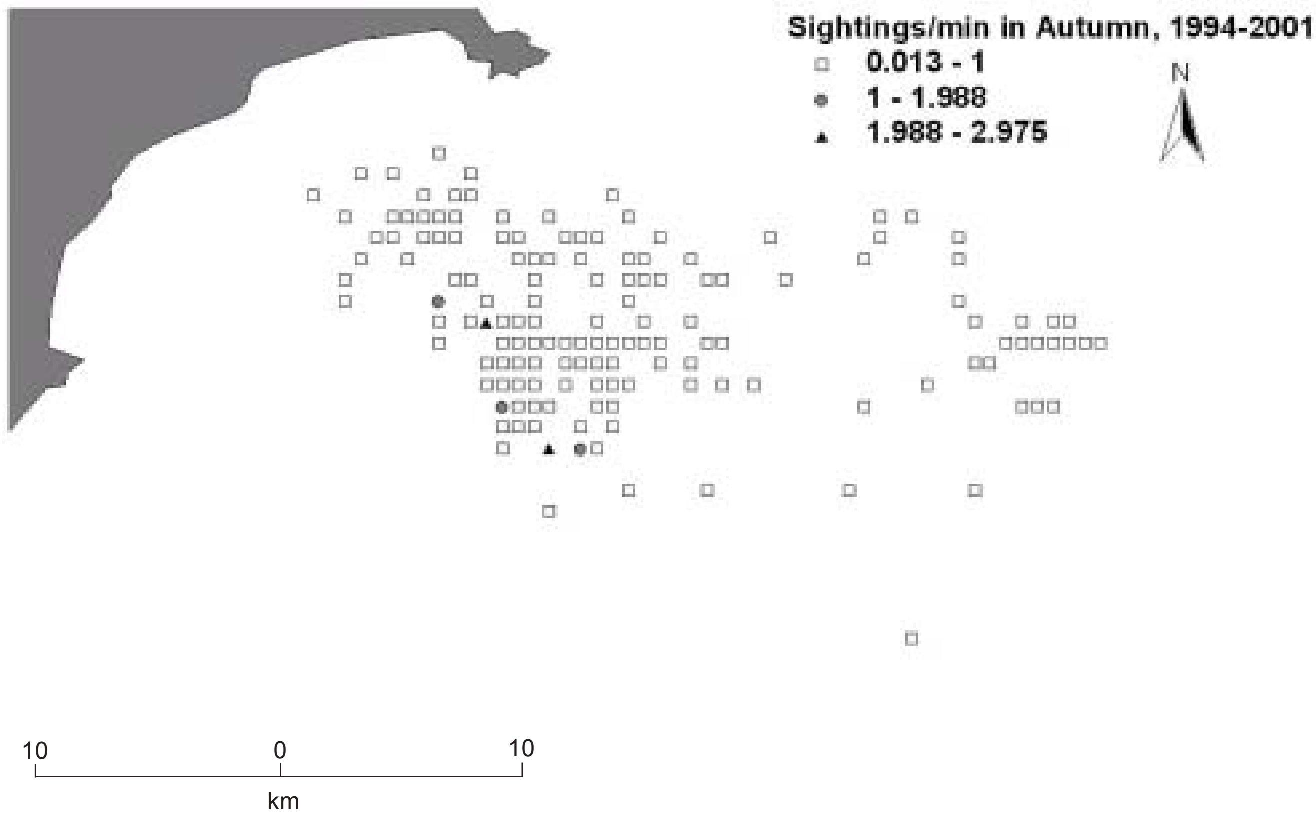


Figure 17. Sighting rates of sperm whales (sightings/min) off Kaikoura in autumn, 1994–2001.

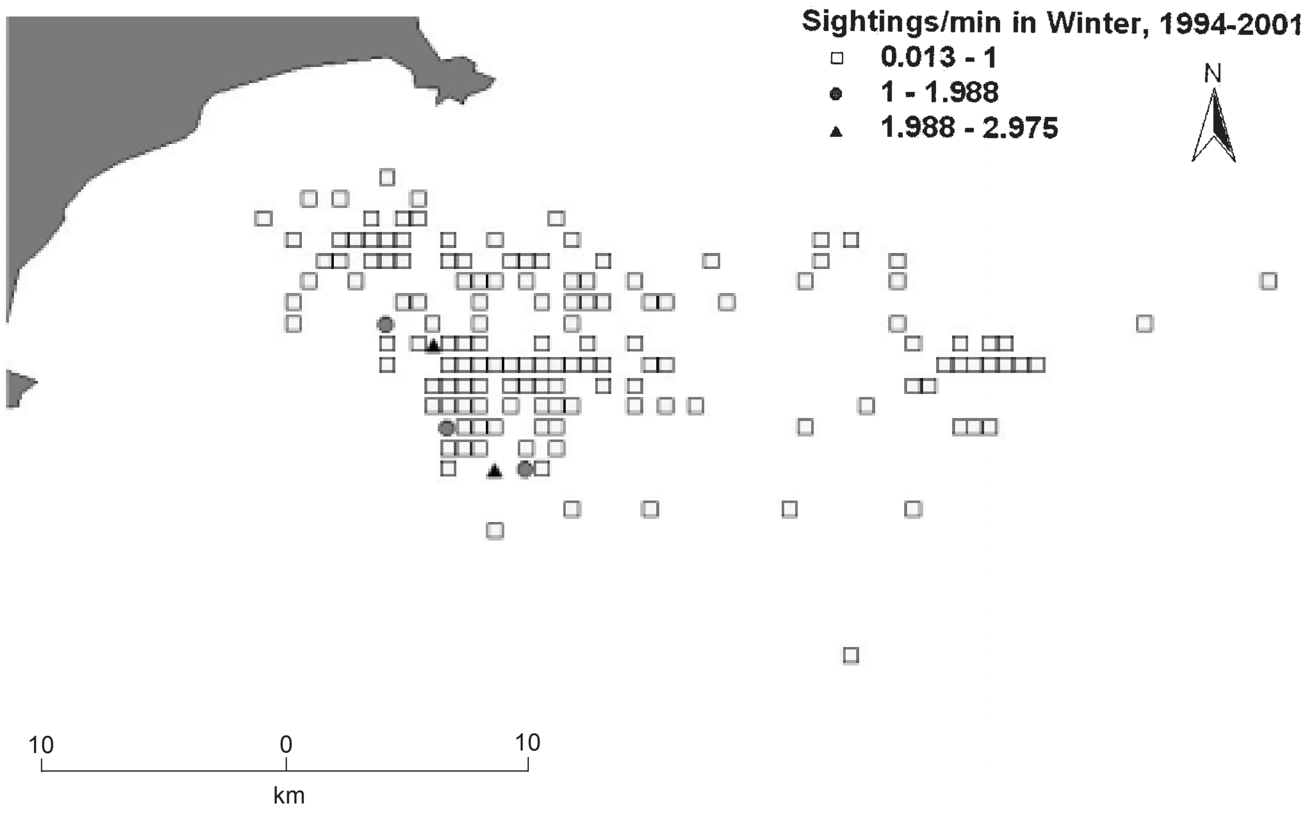


Figure 18. Sighting rates of sperm whales (sightings/min) off Kaikoura in winter, 1994–2001.

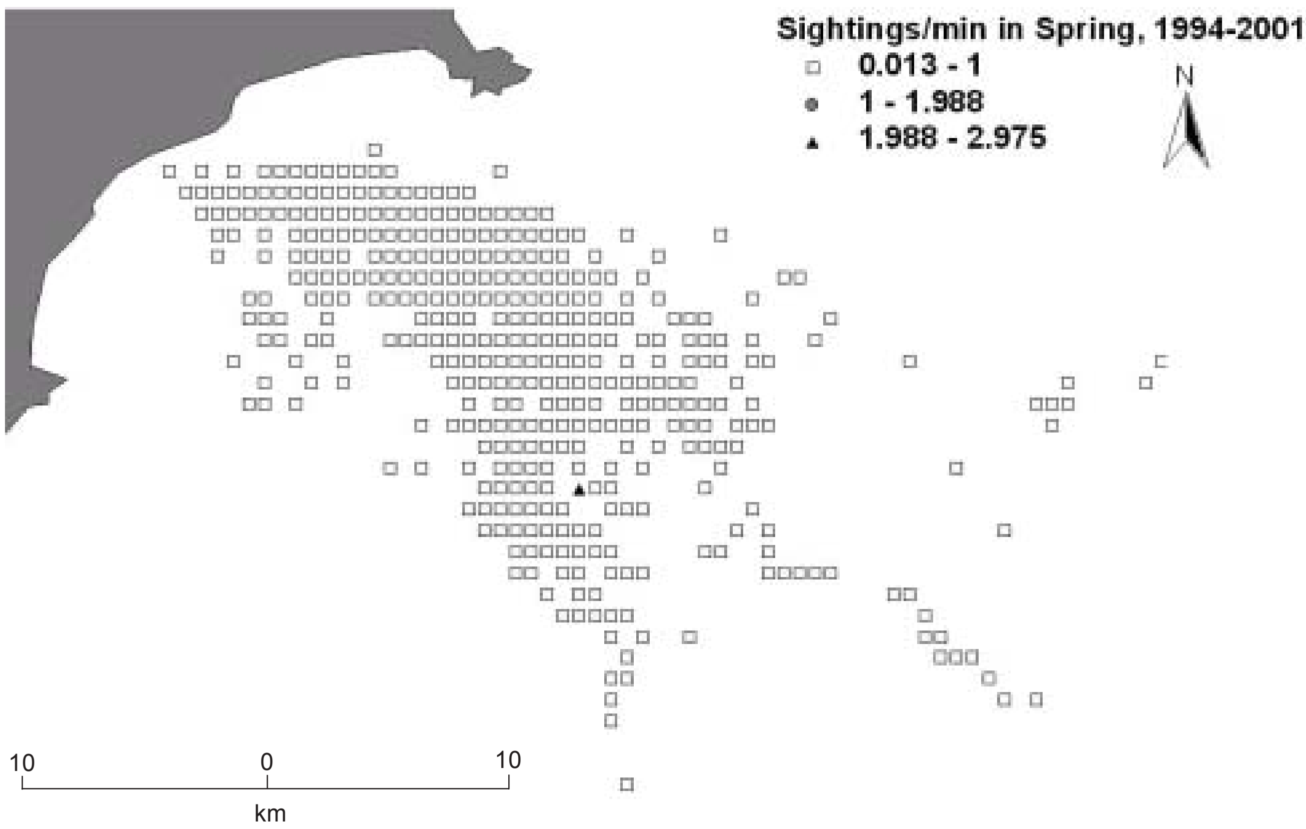


Figure 19. Sighting rates of sperm whales (sightings/min) off Kaikoura in spring, 1994–2001.

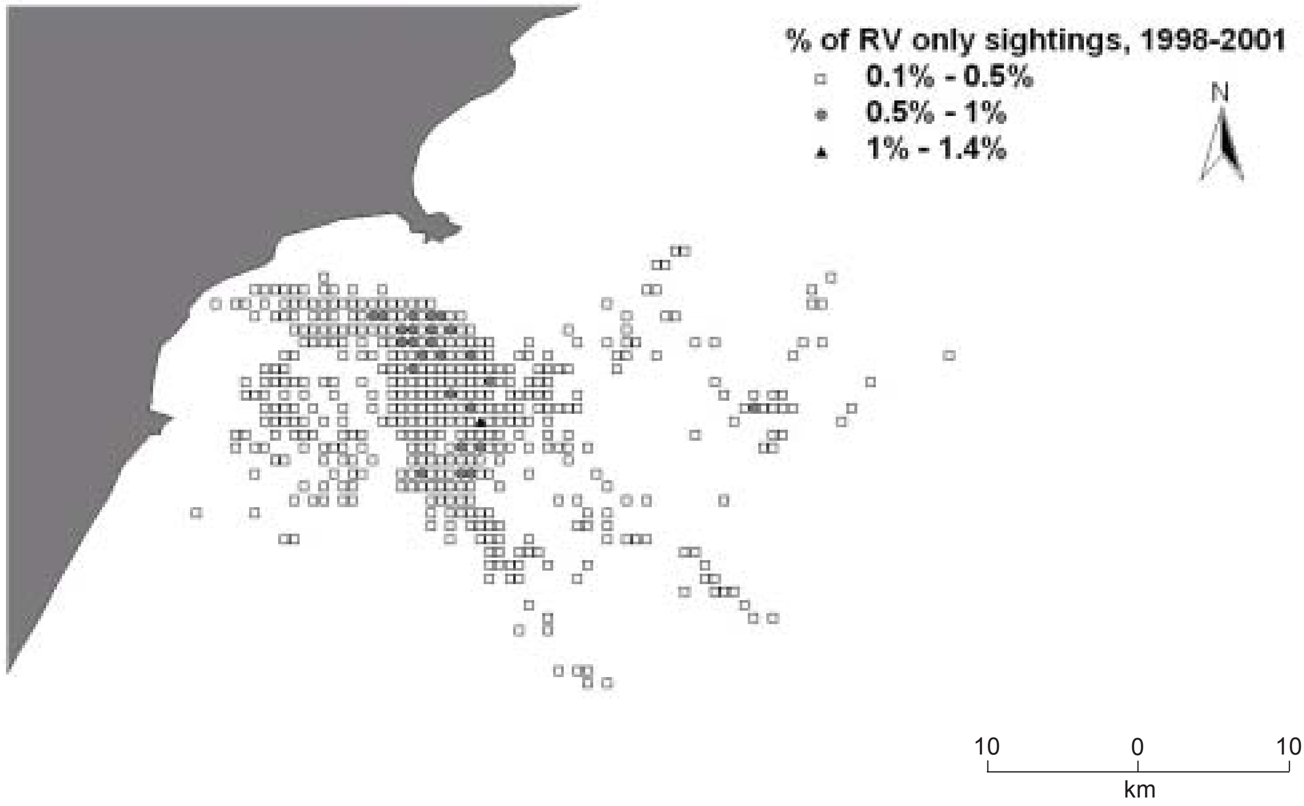


Figure 20. Sightings of sperm whales off Kaikoura with only the RV present, 1998–2001.

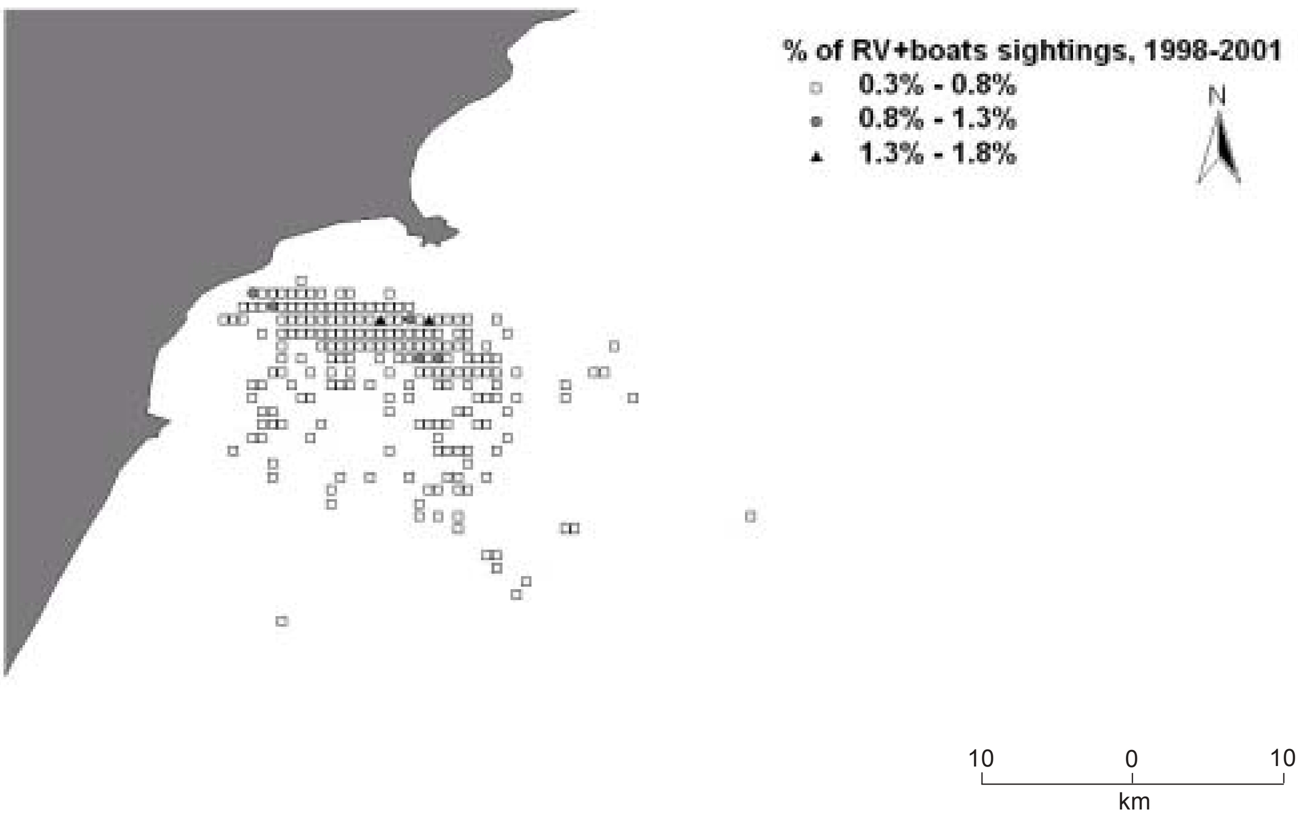


Figure 21. Sightings of sperm whales off Kaikoura with the RV and WWboats present, 1998–2001.

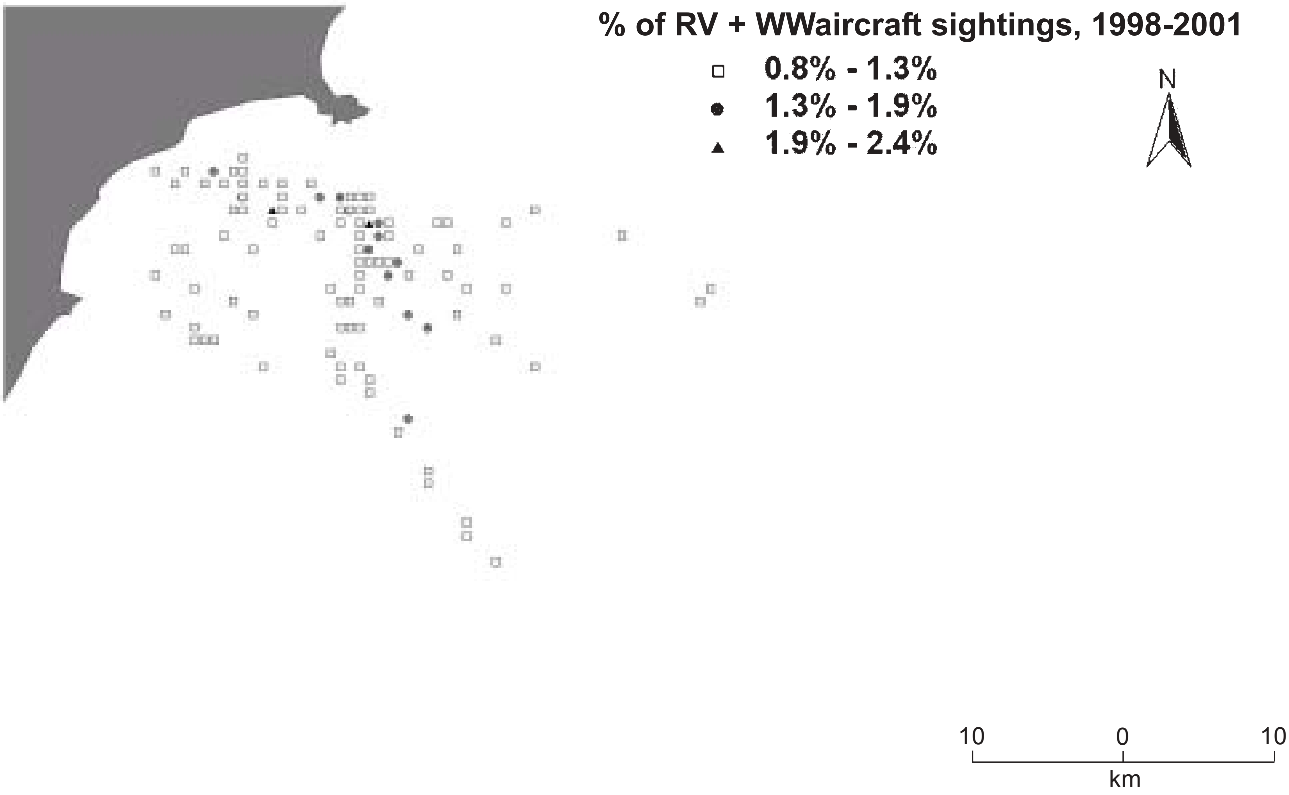


Figure 22. Sightings of sperm whales off Kaikoura from the RV, with WWaircraft present, 1998–2001.

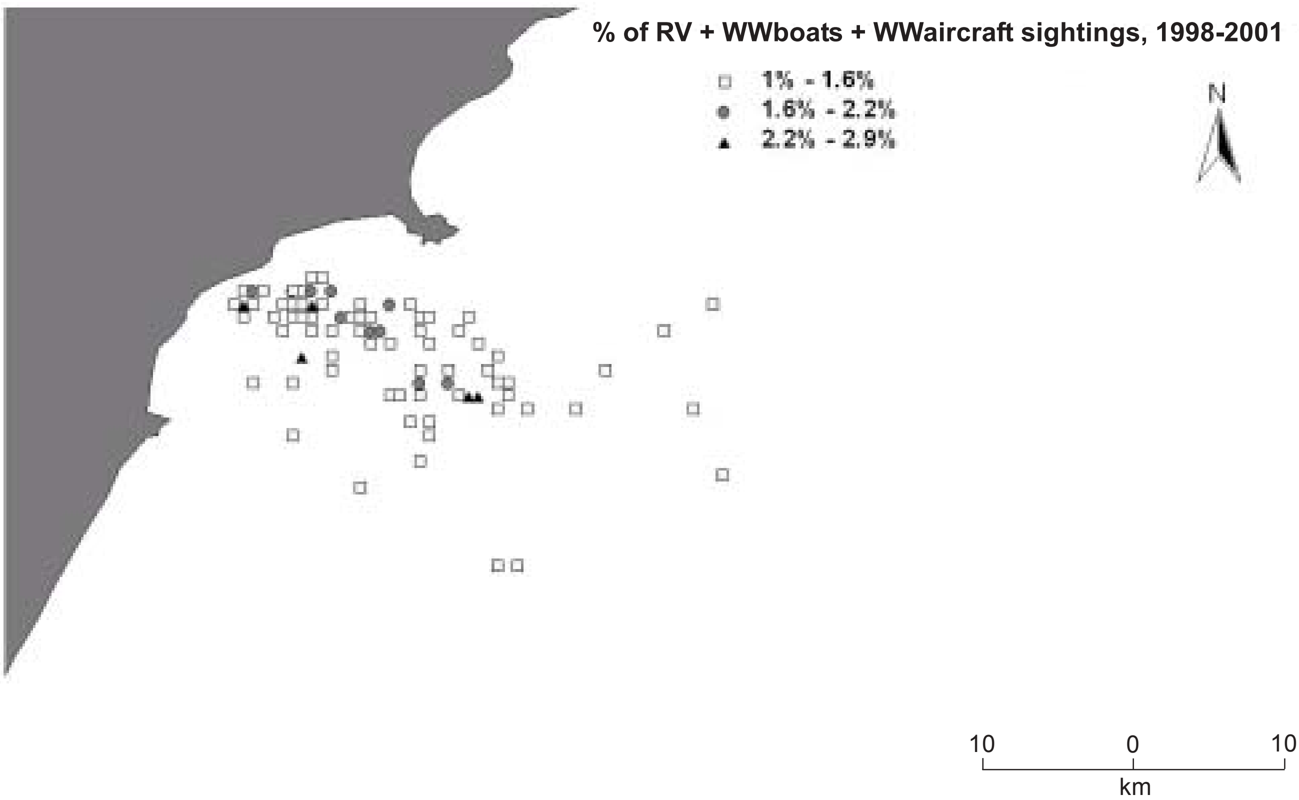


Figure 23. Sightings of sperm whales off Kaikoura from the RV, with WWboats and WWaircraft present, 1998–2001.

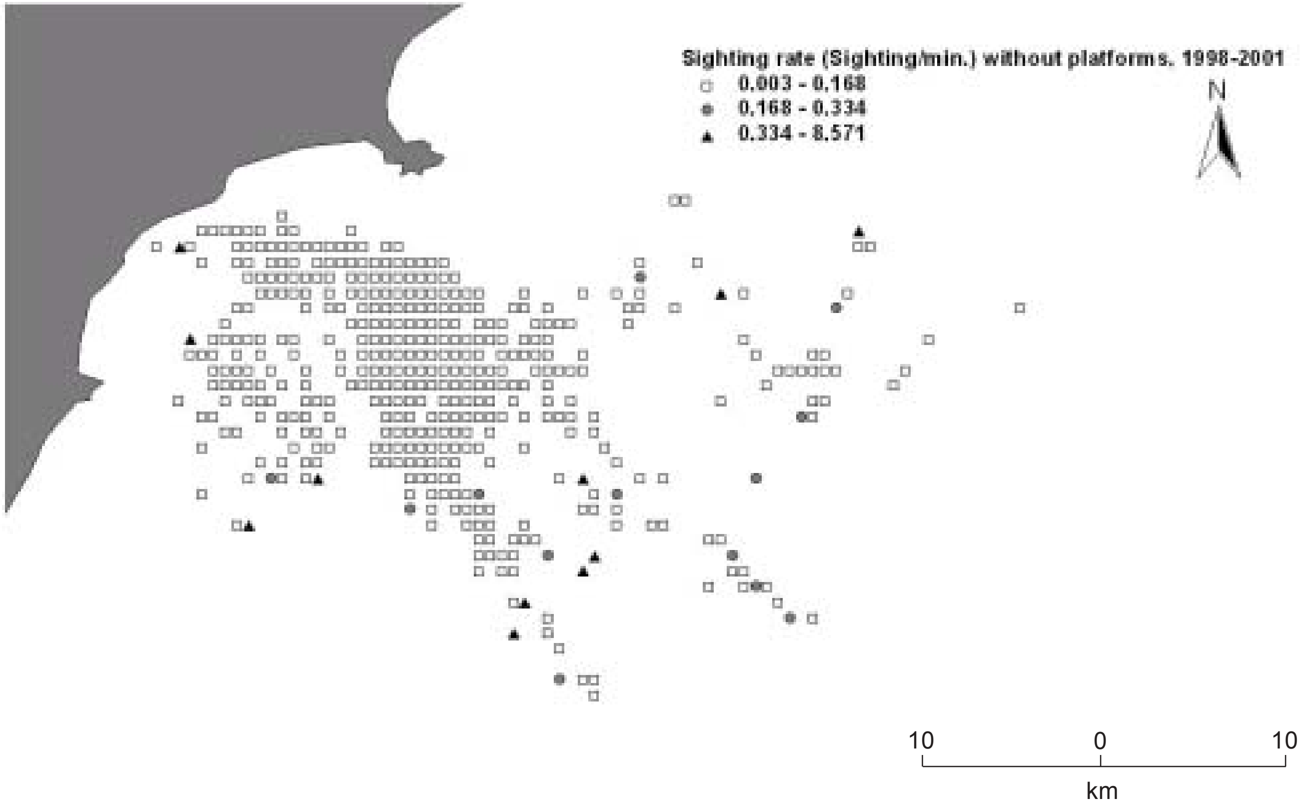


Figure 24. Sightings of sperm whales off Kaikoura from the RV, without WWPs present, 1998–2001.

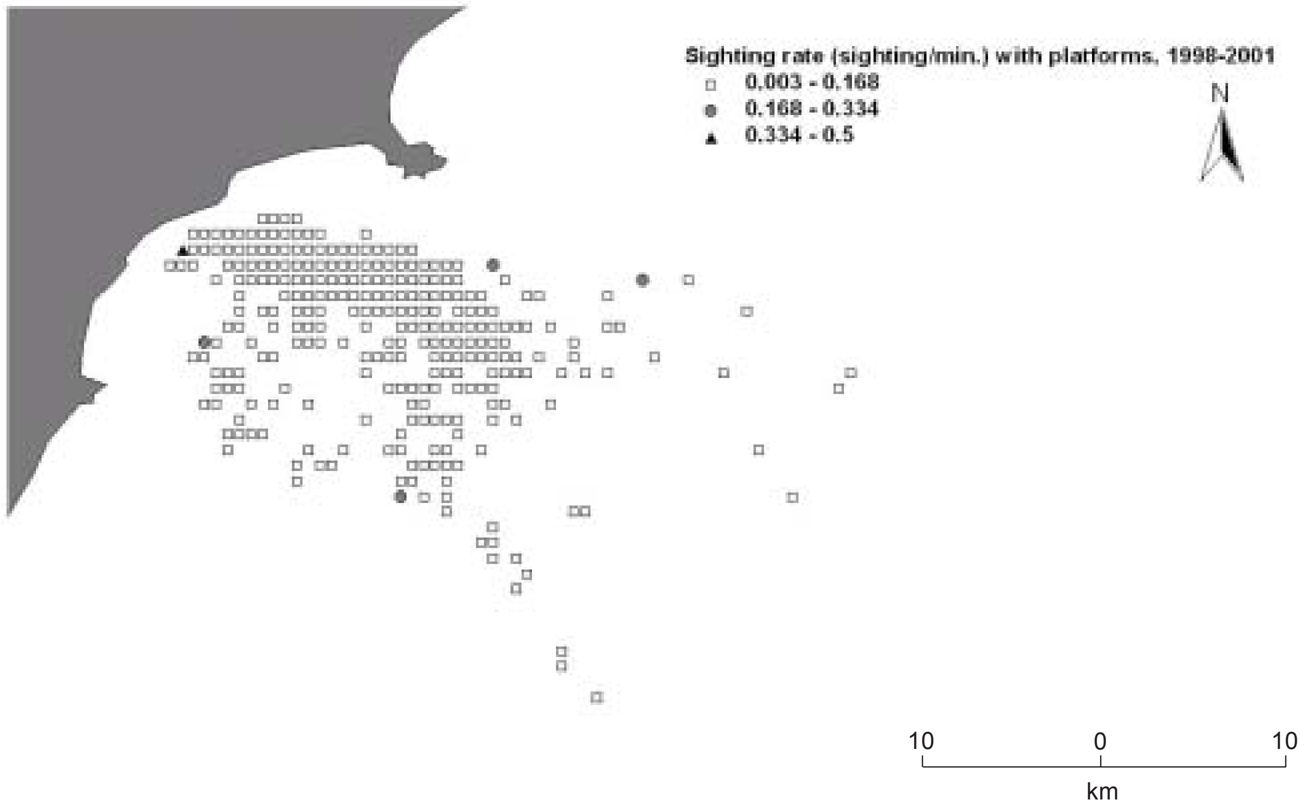


Figure 25. Sightings of sperm whales off Kaikoura from the RV, with WWPs present, 1998–2001.

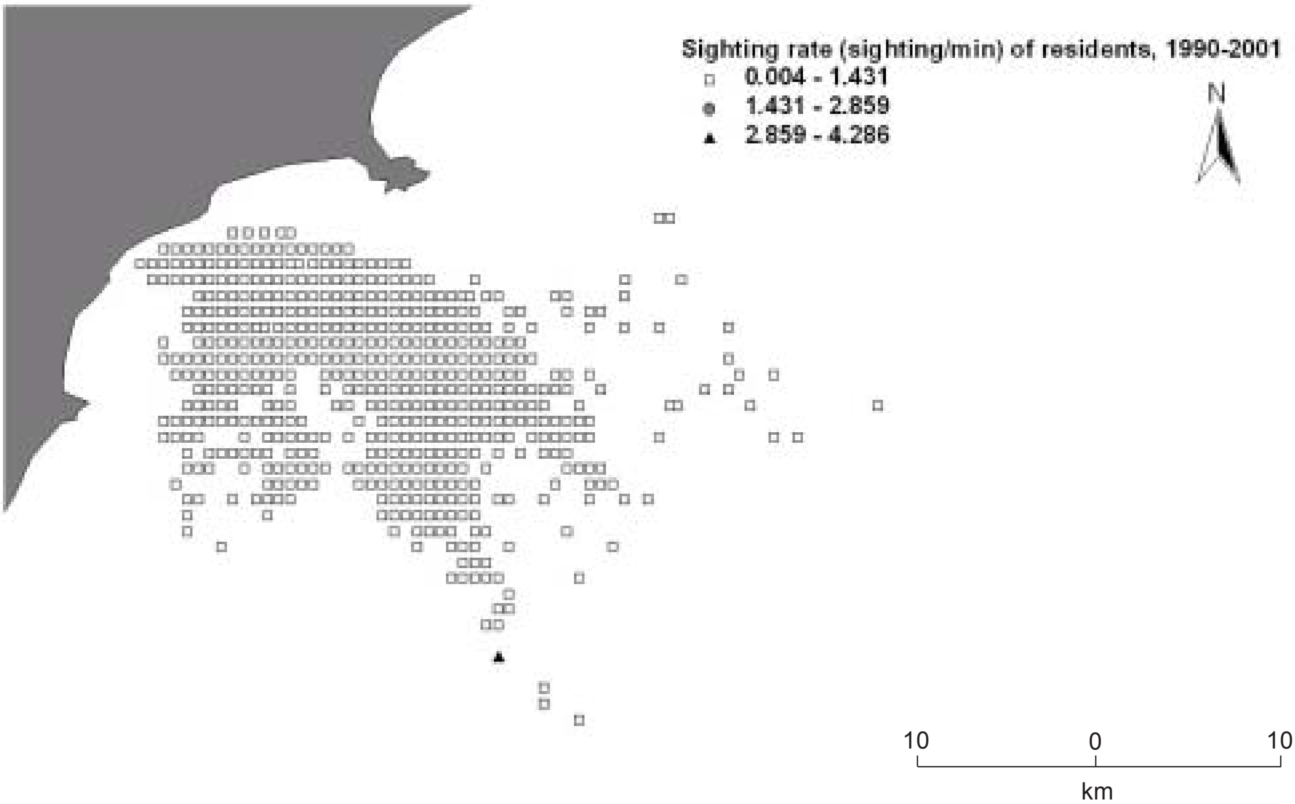


Figure 26. Sightings of resident sperm whales off Kaikoura, 1990–2001.

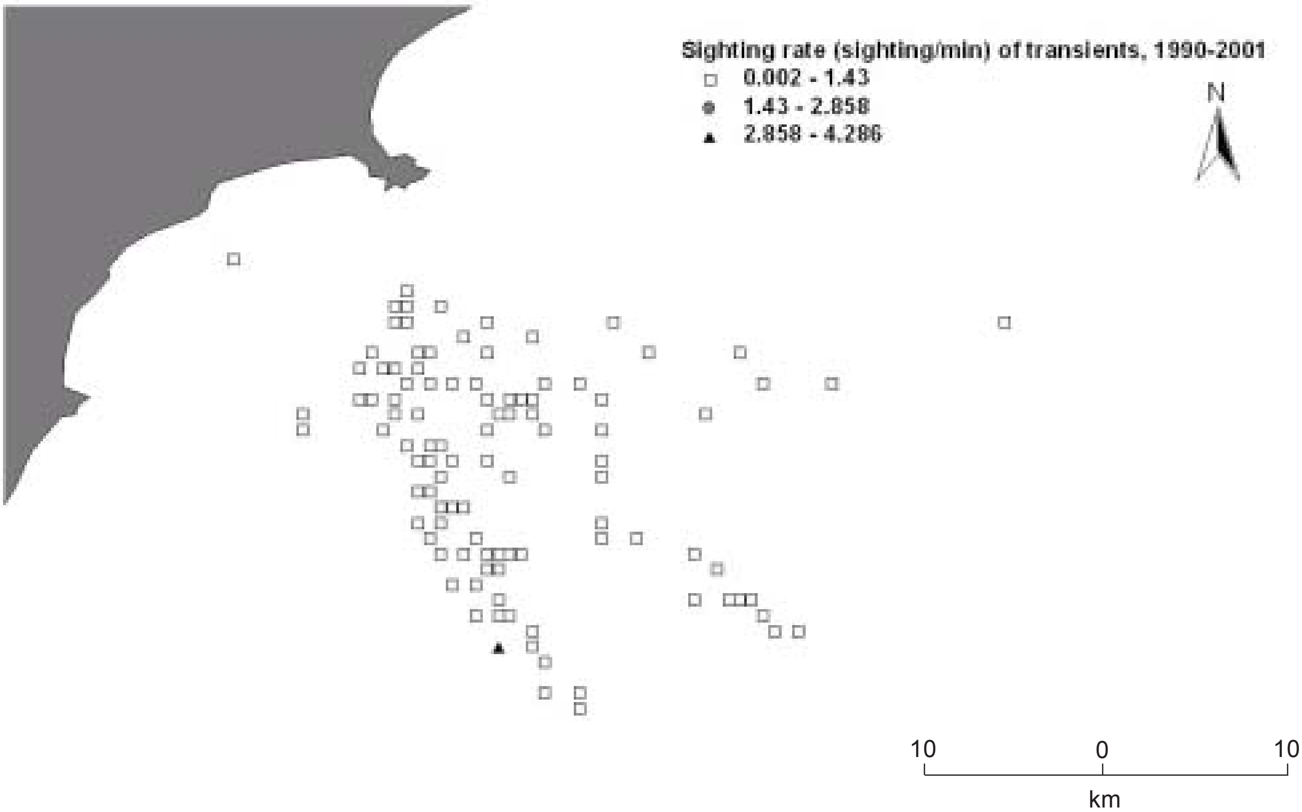


Figure 28. Sightings of transient sperm whales off Kaikoura, 1990–2001.

This number will be an optimistic estimate, because whales may surface at the same or similar times and some surfacings may not be noticed in poor light conditions. Further, skippers do not have perfect knowledge of where whales are. Hence, this estimate should be seen as an absolute maximum number of available surfacings.

We next used data provided by Whale Watch™ Kaikoura Ltd to estimate the number of trips per day and the number of sightings per trip. This allowed calculation of the average number of sightings per day. From observations made from the RV, we can estimate the number of those encounters that would occur with one, two or three WWboats in attendance, and therefore the number of encounters with at least one WWP present (Table 55).

In summer and autumn, resident whales will be accompanied by at least one WWP for around 40% of their surfacings between 0730 h and 1730 h. During the cooler months of the year fewer trips are made, and this proportion drops to less than 20% in winter and less than 30% in spring.

The above estimates probably underestimate the proportion of surfacings for which whales are accompanied by boats. It was assumed that whale watching is being carried out over 10 hours, regardless of season. Shorter days, particularly in winter, will increase the proportion presented in Table 55. Additionally, as mentioned above, not all surfacings will be accessible to WWboats. Furthermore, effort data were only available from Whale Watch™ Kaikoura Ltd, which again leads to an underestimation of accompanied encounters. It is therefore likely that, at least in summer, more than half of the surfacings of a resident whale are observed by WWPs. These estimates apply only from 0730 h to 1730 h, and in good weather. Outside these times, and in poor weather, the whales are not accompanied by WWboats.

TABLE 55. CALCULATION OF PERCENTAGE OF DAYLIGHT SURFACINGS THAT ARE ACCOMPANIED BY WWPS.

	SUMMER	AUTUMN	WINTER	SPRING
Average number of residents available to WWPs[1]	5.2	3.4	3.8	4.2
Average length of dive cycle (min)[2]	53.2	50.4	47.5	50.4
Number of cycles per whale between 0730 and 1730 h	11.3	11.9	12.6	11.9
Number of surfacings	58.8	40.0	47.3	50.0
Average number of trips/day[3]	9.1	4.9	2.0	6.4
Average number of sightings/trip[3]	3.2	3.9	3.9	2.7
Average number of sightings/day[3]	29.2	19.0	7.9	17.4
Average number of sightings with 1 WWP/day[1]	20.7	11.1	7.0	11.4
Average number of sightings with 2 WWP/day[1]	7.5	7.5	1.0	5.6
Average number of sightings with 3 WWP/day[1]	1.0	0.3	0	0.4
Number of separate sightings with ≥ 1 WWP/day	24.7	15.0	7.5	14.3
Minimum daily % of surfacings with ≥ 1 WWP	42.1	36.7	15.8	28.6

Data Sources: [1]This study; [2]Jaquet et al. (2000); values for autumn and spring are interpolated between summer and winter values, since no autumn and winter data were available from the paper); [3]Whale Watch™ Kaikoura Ltd.

4. Discussion

To maximise data quantity and allow different questions to be asked, we analysed four Data Sets: (1) all data gathered from the RV, whether or not an ID was gained from the whale in question; (2) data gained from the RV from encounters in which whale ID was known; (3) as Data Set 2, used for comparisons between resident and transient animals; and (4) data collected from shore. Each Data Set has unavoidable strengths and weaknesses. Data Set 1 maximises sample size for questions of vessel impact, but does not allow for differences among individual whales, as Data Sets 2 and 3 do. Data Set 4, collected from shore, eliminates possible effects of the RV, but like Data Set 1 cannot factor out differences among individual whales. For convenience, results which reflected a significant effect of vessel presence are summarised in Table 56.

The most dominant influences in Data Set 1 were yearly and seasonal factors and, frequently, their interaction. In most cases, effect sizes were small to medium ($0.1 < f > 0.25$; cf. Kirk 1996). In comparison, effect size of WWP presence was typically very small ($f < 0.1$), except for the RV/WWaircraft analysis of number of blows, which resulted in a small effect ($f = 0.13$).

This is the first study to show the importance of differences among years in sperm whale behaviour off Kaikoura. Yearly variation in surface behaviour and feeding success has been described for sperm whales around the Galápagos Islands (Whitehead et al. 1989; Waters & Whitehead 1990; Whitehead 1996). These variations observed could best be explained by annually changing oceanographic conditions, such as the occurrence of Southern Ocean Oscillation (Whitehead et al. 1989; Waters & Whitehead 1990). There are no data available to assess annual fluctuations of oceanographic conditions in the Kaikoura Canyon (Gibbs et al. 2000), so we cannot say whether the same explanation holds at Kaikoura. Similarly, nothing quantitative is known about annual changes in abundance and distribution of squid (*Moroteuthis* spp.), the main prey of sperm whales in the Kaikoura area (Gaskin & Cawthorn 1967). Because squid generally have life spans ranging from 12–18 months, there is little overlap of generations. As a consequence of this, their populations typically vary a great deal from year to year (O'Dor & Webber 1986; Jaquet et al. 2000). Hence, the behaviour of their predators is also expected to vary year to year.

It is worth noting that year is very rarely the only significant main factor. More frequently, year is significant in interactions with season, ID or boat. This can arise because some individuals are seen only in certain years, which renders year and ID significant along with their interaction. This is especially probable considering the importance of ID and season in the analysis of Data Set 2, and their associated medium-to-large effect sizes.

The analysis of Data Set 2 (daily averages with ID) confirms the importance of seasonal differences and the small influence boats have on the ventilation patterns of sperm whales.

Seasonal changes in distribution and dive patterns have been described previously and interpreted as signs of changes in diet (Childerhouse et al. 1995; Jaquet et al. 2000). Mean surface times during summer and winter from this

TABLE 56. OVERVIEW OF ANALYSES WHICH RESULTED IN SIGNIFICANT PLATFORM EFFECTS.

RESPONSE VARIABLE	PRESENCE OF ...	DATA SET	EFFECT
Mean blow interval	None or RV	1 + 4	decrease
	None or WWboats	4	decrease
CV of mean blow interval	None or WWboats	1	decrease
Median of blow interval	None or WWP	4	decrease
	None or RV	1 + 4	decrease
Number of blows/surfacing	RV or RV + WWaircraft	1	increase
	RV or RV + WWaircraft	3: Residents	increase
Surface time	RV or RV + WWP	1	increase
	RV or RV + WWboats	2	decrease
Time to first click	RV or RV + WWP	1	decrease
	RV or RV + WWboats	1	decrease
	RV or RV + WWboats	3: Residents	decrease
Frequency of heading change	RV or RV + WWP	1	increase
	RV or RV + WWP	3: Residents	increase
	RV or RV + WWboats	1	increase
	RV or RV + WWboats	3: Residents	increase
Amount of heading change	RV or RV + WWP	1	increase
	RV or RV + WWaircraft	1	increase
	RV or RV + WWaircraft	2	increase
	RV or RV + WWaircraft	3: Residents	increase
Frequency of aerial behaviour	RV or RV + WWP	1	decrease
	RV or RV + WWP	3: Residents	decrease
	RV or RV + WWboats	1	decrease

study (9.23 min and 8.3 min respectively) are comparable to those reported by Jaquet et al. (2000) (9.3 min and 8.8 min respectively). Similarly, summer distribution followed the pattern described by Jaquet et al. (2000). In contrast, winter distribution differed: Jacquet et al. (2000) described a more evenly distributed pattern, while we observed a more concentrated distibution. This could indicate changes in winter prey distribution between the study periods (1990–1994 for Jaquet et al. (2000); 1994–2001 for this report). Alternatively, it could be due to the fact that we used standardised sighting rates (consequently reflecting our focus on the canyon area to observe whale watching interactions) while Jaquet et al. (2000) plotted sighting positions only.

One of the clearest results of our analyses is that differences among individual whales have a crucial role, often swamping the effect of other factors. ID is a significant factor in almost all analyses, often having a medium to large effect ($0.25 < f > 0.4$). Sperm whales off Kaikoura generally display rather predictable ventilation and diving behaviour. The majority of whales spend between 7 and 14 minutes at the surface and approximately three quarters of all dives last between 30 and 49 minutes (Jaquet et al. 2000). Nevertheless, this study indicates that individual whales display ventilation and vocalisation patterns which are consistent, but patterns vary between individuals. Gordon et al. (1992) and MacGibbon (1991) described similar results.

The differences between individuals can be explained only partially by differences between transient and resident animals. Gordon et al. (1992) speculated that differences could reflect different feeding strategies and that whales therefore may attempt to maintain exclusive 'territories'. While neither Gordon et al. (1992) nor we were able to observe 'territorial' behaviour, Whale Watch™ Kaikoura Ltd skippers have reported resident animals swimming towards transient individuals that come closer inshore. The transient animals consequently turned around and left the area (L. Baxter, Kaikoura, pers. comm.). It is not clear whether this is 'territoriality' in the usual sense. To our knowledge, 'territoriality' has not been described for any cetacean.

In general, the presence of WWboats and/or WWaircraft had little effect on the ventilation patterns of resident sperm whales. Interestingly, while decreases in measures relating to blow interval (mean, CV and median) were chiefly linked to boats (WWboats and RV), number of blows per surfacing were found to increase when WWaircraft were present (Table 56). However, effect sizes are typically small (approx. f = 0.1), indicating that these changes, while statistically significant, are small, and hence probably of little biological consequence. Likewise, duration of surface time was significantly increased by boat presence in Data Set 1, but again, the effect size was small. A boat effect on surface time was evident in analysis of Data Set 2, in which presence of WWboats decreased surface time. This corresponds with the data of MacGibbon (1991), who detected shortened blow intervals and surface periods in the presence of WWboats. Gordon et al. (1992) also observed reduction in blow intervals and surface time when not considering ID in the analysis.

In contrast to the results from the analysis of ventilation patterns, directional headings, aerial behaviours as well as time to first click showed clear impacts of vessel presence. Whales turned more often and more sharply in the presence of WWPs. It is interesting to note that boats seem to have most influence on the frequency of heading changes, while aircraft apparently cause whales to turn more sharply (Table 56). Generally, WWboat behaviour around whales was predictable and relatively constant. Boats, once within range, approached relatively slowly, positioning themselves to the back and side of the whale. However, because most of the time boat skippers find whales visually rather than acoustically, they typically approach from further away, which necessitates a longer period at high speed. Also, to maximise the quality of ID photographs, the RV is typically positioned directly behind the whale, rather than behind and to the side (the favoured position of WWboats). It seems likely that directly behind is less disturbing. By contrast, Gordon et al. (1992) did not detect effects of boat presence on changes in heading, but this result could reflect their much smaller data set.

Surprisingly, we recorded aerial behaviours more often with only the RV present. No comparable data are available from earlier studies at Kaikoura; aerial behaviours were either too rarely observed for statistical analysis (MacGibbon 1991) or not recorded (Gordon et al. 1992). Breaching and lobtailing are behaviours which are relatively often performed by sperm whales, but usually by females and immature animals, rather than by maturing or mature males (Waters & Whitehead 1990). These authors found that most breaching and lobtailing is done in social contexts, and also that the rate of aerial behaviours may depend on foraging success. Therefore, there are no indications that these behaviours in sperm whales are a response to outside stimuli. However, the inclusion in our analysis of 'head-outs', which were not considered in the study by Waters &

Whitehead (1990), may account for the apparent increase in aerial behaviours in response to the RV. Following cues from the directional hydrophone, we always attempted to position the RV as close as possible to where we expected the whale to surface. This was done to avoid the need for high-speed approaches from a distance. On several occasions, whales surfacing close to the RV performed head-outs before the first blow. Therefore, the fact that the RV was, on average, closer to surfacing sperm whales than WWboats (which use directional hydrophones less systematically) may explain the increase of aerial behaviours in the presence of the RV.

Sperm whales also responded to the presence of WWPs with changes in vocal behaviour. In Data Set 1, time to first click decreased in the presence of WWPs. Once again, in Data Set 2, variability due to individual differences swamped this effect. However, more detailed analyses detected changes in time to first click due to boat but not aircraft presence. Since little airborne sound from aircraft penetrates into the water column (Richardson et al. 1995), this is not surprising. The significant result from Data Set 1 seems to reflect differences between residents and transients. While residents significantly decreased time to first click, transients increased this time interval by almost 50%. This may be in response to boat noise; transient whales may start clicking only once the noise from boats has fallen below normal ambient noise levels.

How severe are these changes for the sperm whales? How important are they biologically? Commonly, biological importance of anthropogenic impacts is associated with long-term effects on reproductive parameters and/or distribution (IFAW et al. 1995). Long-term data on sperm whale sightings are available and are included in this report when appropriate. However, no corresponding data for whale watching effort are available. Thus, it is difficult to assess the biological consequences of the observed changes. Gordon et al. (1992) estimated that a reduction of surface time by 17% could translate into feeding time being reduced by as much as 36%. This study had a much larger sample size of observations, yet did not detect a clear reduction in surface time. In addition, all significant changes were associated with small effect sizes. Thus, it is likely that the observed influences of WWPs on whale behaviour are not very important biologically. In general, resident whales are much more tolerant of boats and aircraft than are transients; residents appear to have learned that these WWPs do not present a significant threat.

Mark-recapture analyses of ID photographs have shown that in any one season 60–100 sperm whales visit Kaikoura (Childerhouse et al. 1995; Cairney 1998). The latest analyses (Letteval et al. 2002) indicate that, on average, there are 13.8 (Jackknife S.E. = 1.3) whales (including residents and transients) in the study area on any given day. About a third of the whales we see at Kaikoura are transients, which are seen once only (Jaquet et al. 2000). This implies that on any one day there are about nine residents in the study area. These residents, however, are not always found inshore, within the range of the WWboats. Hence the whale watching effort is necessarily distributed over a small number of individuals. On summer days during good weather, an individual resident will be accompanied by WWboats for about half of the number of times it surfaces between 0730 h and 1730 h.

One of the more obvious consequences of high boat traffic in an area where whales or other marine mammals congregate is the possibility of a collision between animals and boats. Such accidents have been reported for numerous species and locations (Sears et al. 1990; George et al. 1994; Wells & Scott 1997; Stone & Yoshinaga 2000; IFAW 2001) and can have severe impacts on the conservation of some species; for example, the Florida manatee (*Trichechus manatus latirostris*) (Ackermann et al. 1995) and the northern right whale (*Eubalaena glacialis*) (Kraus 1990). In addition to causing injury or death to the animal involved, a boat strike can also cause injuries and deaths to passengers on board the vessel.

In some marine mammal species, certain individuals or groups of individuals seem to be more likely to be struck by boats. For example, almost all boat strikes of bottlenose dolphins in Florida involved animals 'compromised' due to illness, presence of a calf or young age (Wells & Scott 1997). Similarly, young northern right whales and Hector's dolphins seem to be more vulnerable to such accidents than older individuals (Kraus 1990; Stone & Yoshinaga 2000). Thus, lack of experience with vessels may play a role in strikes. This seems particularly relevant for the transient individuals off Kaikoura, which appear to be less tolerant of boats and aircraft, possibly due to a lack of experience with them.

It has also been suggested that habituation may lead to increased risk of collisions (Stone & Yoshinaga 2000). While habituation is a well-studied phenomenon in land animals, it has not been studied in detail in marine mammals (Richardson et al. 1995), except for evidence that harbour porpoise (*Phocoena phocoena*) habituate to pingers (Cox et al. 2001). Therefore it is difficult to predict how habituation, if it does occur, alters the risk of whale–boat collisions in the whale watching context. It can be expected that habituation increases the risk of collisions if habituated animals, for example, fail to dive, increase time spent at the surface or actively approach boats. While comparable changes have been detected by this and other studies (see section 1.1), most of these changes do not seem to be results of habituation and, more importantly, they are small and thus unlikely to increase significantly the risk of boat strike.

However, one other factor—boat speed—definitely increases the risk of boat strikes. Boat speed crucially determines the probability of people on the boat spotting cetaceans (Asmutis-Silvia 1999). Intensive research on sighting probabilities of cetaceans during surveys indicates clearly that sighting rate decreases with increasing speed (Buckland et al. 1993). Thus, the increasing speed capability of WWboats has become of concern (Asmutis-Silvia 1999). Similar to the development off New England, WWboats off Kaikoura have also become capable of increasing speed. The cruising speed of the catamarans built prior to 1999 was 25 knots (Whale Watch™ Kaikoura Ltd Information Kit), while the newest vessels can apparently reach speeds of up to 35 knots when fully loaded.

While conditions leading to boat–whale collisions are difficult to determine, the risk of such an accident, while apparently small, is undeniable. This risk would be expected to increase in proportion to the number of boats frequenting the area, and the speed at which these travel.

5. Conclusions and recommendations

5.1 LIMITATIONS OF THIS STUDY

Current whale watching operations do not influence the behaviour of sperm whales in a manner which seems to indicate severe disturbance or harassment. There are several limitations to this statement which necessitate cautious recommendations:

- No data on the responses of sperm whales to WWPs are available from before whale watching started. Thus, while comparisons between whales with and without WWPs can be made, no true baseline data on undisturbed whales are at hand. It could be argued that since transient individuals are very rarely, if at all, visited by WWPs, this group could be used as true control. However, because of the different use of the Kaikoura area by these two groups, and the fact that whales without WWPs in their vicinity may still be influenced by boat noise originating some distance away, it is questionable how useful such an approach would be.
- Despite the fact that this study observed over 60% more sperm whale surfacings than the two previous studies put together, sample size restricted analyses to presence or absence of vessels as a potential influence on whale behaviour. No distinctions could be made between the number of WWboats and/or WWaircraft, because of the small sample size of encounters with different numbers of boats and with aircraft. The aircraft do not operate as frequently as the WWboats, and because of their much greater speed, tend to operate over a wider area. Hence encounters with WWaircraft are less frequent than would be expected.
- We still know very little about some aspects of the Kaikoura sperm whales. There is no reliable information on where they come from nor where they go to when they leave our study area. Consequently, it is not clear how important Kaikoura is to South Pacific sperm whales. Considering the presence of transient animals, it can be assumed that other feeding grounds are available. On the other hand, the fact that numerous whales have been re-sighted off Kaikoura during several seasons or even years points to a crucial role of the canyon for at least these resident animals. Therefore, further development of the whale watching industry should be cautious, and based on precautionary principles.
- Although this study is the longest investigation into whale watching impacts off Kaikoura, it is not a long-term study. Sperm whales live to at least 60 years (Rice 1989). Three years of study of whale watching cannot, therefore, be considered an extensive longitudinal study. While we have distributional data for the last decade, no parallel data on whale watching effort are available. It is thus impossible to assess long-term changes quantitatively.

5.2 MANAGEMENT OPTIONS

Considering the results from this study and operational limitations, several management options are available:

1. Restrict whale watching activities to less than their current level, or abandon them entirely, on the grounds that current levels of whale watching cause impact. While consistent with the data, this management action is probably unwarranted, because effects of the current level of whale watching appear to be sustainable.
2. Maintain the current level of permitted whale watching, but issue no further permits. This study found responses to vessel presence at the current level of whale watching. Whale Watch™ Kaikoura, even at their busiest, are currently using less than 60% of their permitted number of trips. Hence maintaining only the current permits could still allow whale watching to expand significantly.
3. Issue further permits, but require effort to be spread across all animals in the area. Transient sperm whales are rarely, if at all, visited by WWboats. Therefore, pressure from trips could be spread more equally, thus giving resident animals more surface time without WWboats in the vicinity. Our observations do not support this option, for two reasons: First, transient animals respond more to boat presence than resident individuals. Therefore, it does not make sense to subject the most sensitive whales at Kaikoura to whale watching. In addition, such a regulation would likely cause operational difficulties. Transient animals are further offshore and less predictable in their distribution. Thus, it would be difficult to require some proportion of daily encounters to focus on transient individuals.
4. Issue further permits for additional WWboats and/or trips. This option might be seen as desirable for economic reasons. The data sets provide some guidance on how many trips could be added (see Table 55), but cannot predict whether there is a level at which whales will abandon Kaikoura or react in some other negative way. Because they are most sensitive to disturbance, transients should not be targeted. In this case, the only option would be to increase the number of boats/trips targeting the residents. During daylight hours in summer, WWboats accompany resident whales on about 50% of their surfacings (see section 3.8). It would be possible to increase this, if managers were comfortable with residents spending very little time on the surface alone.

Four observations argue against issuing more permits:

- Considering that current levels of whale watching cause impacts, it may not be desirable to substantially increase the level of whale watching.
- Establishing competition on the water would probably not be in the whales' interest, as it would likely lead to more speed to get to whales first, and more aggressive behaviour around whales. It is difficult to see how increasing competition could decrease impacts.
- Whale Watch™ Kaikoura is presumably filling the available demand, yet is not offering as many trips as it is permitted to. There may not be sufficient demand to justify additional operators.
- The value of the experience gained by passengers might be diminished.

The existing data best support option 2 above.

5.3 RECOMMENDATIONS

- The current rules governing the number of vessels, and their conduct, around whales appear to be generally effective in minimising harassment of whales by commercial WWvessels. Our observations show no need to change the regulations. The conduct of current whale watching skippers around whales is generally good.
- Waterjet propulsion, in general, is much quieter underwater than propellers, and safer for whales in the event of a collision. Any new commercial WWboats should be fitted with waterjet drives.
- Directional hydrophones can reliably indicate the direction and, with experience, the approximate range of submerged whales. They are used only sporadically by whale watch skippers, depending on the skipper and the number of whales in the vicinity. It may be advisable to increase their use to avoid boats roaming an area while waiting for a whale to surface. This would decrease the chance of collision between WWboats and whales. Tracking could also be included in the experience for the tourists.
- A monitoring scheme should be put in place in cooperation with the whale watching companies. Whale reactions should be observed on a regular basis, using recognised methods. This would facilitate detection of changes in behavioural patterns in time for management to respond appropriately. While the scheme should be designed and set up in cooperation with the industry, it should be operated independently. Part of the scheme should be regular updates to the industry.

5.4 EDUCATIONAL VALUE OF WHALE WATCHING

Whale watching trips should be educational as well as entertaining; they should provide reliable and up-to-date information. While this project did not attempt to assess systematically the educational value of the trips, we occasionally participated in trips with Whale Watch™ Kaikoura Ltd, and with Wings over Whales (we did not have the chance to fly with Kaikoura Helicopters). On these trips we took note of the contents of the trip narration and any other material intended to increase the educational content.

5.4.1 Trip narration and information provided

Trip narration contains a substantial amount of high-quality, accurate information. The addition of the narrator's interpretations (provided it is made clear that this is an interpretation) can increase the interest value of the commentary, and help build connections between the narrator and listener. However, on the trips in which we took part, narrators sometimes presented incorrect information or implied knowledge of details that are, at best, conjecture. A few examples are listed below (given for illustrative purposes only):

In the context of presenting adaptations to deep diving, nitrogen was described as poisonous. This is not so (70% of the air consists of that element), and does not help explain how marine mammals avoid the 'bends'. At depth, nitrogen is more easily absorbed into the blood, and can 'gas-out' on ascent, forming gas bubbles in tissues and in the blood—this causes the 'bends'. Cetaceans avoid this problem because their lungs collapse at depth, shunting air (and nitrogen) into the nasal passages where gases are not absorbed.

Giant squid was portrayed as 'the favourite prey of sperm whales'. This is untrue. In their analysis of 133 stomachs of sperm whales killed in whaling at Kaikoura and Cook Strait, Gaskin & Cawthorn (1967) found only one beak from a giant squid. The majority of the diet, by far, consists of warty squid (*Moroteuthis* spp.) and groper (*Polyprion oxygeneios*) (Gaskin & Cawthorn 1967). While it is undoubtedly true that sperm whales sometimes take giant squid, passengers should be told that this is extraordinary, and that most of their diet consists of squid less than a metre long (Rice 1989).

When describing the social system of sperm whales, so called 'harem groups' were frequently mentioned, with males 'guarding' or 'defending' groups of females and their offspring. This is an old hypothesis now discredited. Recent studies clearly show that males do not 'take possession' of nursery groups or fight over them (Rice 1989; Whitehead 1993; Weilgart et al. 1996). Rather, mature male sperm whales usually spend only hours with nursery groups, sometimes revisiting the same group several times during a few days. They do not appear to show preferences for certain nursery groups (Whitehead 1993).

In our view, these and other inaccuracies compromise the educational value of the tours.

5.4.2 Recommendations for improvement of educational content of whale watching

Steps to improve the content of the narration have been undertaken. Staff of Whale Watch™ Kaikoura Ltd and Wings over Whales attended a course for marine mammal tour operators that we ran in 2000, and we are currently communicating with one of the companies regarding new narration guidelines. Further means to ensure correct and up-to-date information could include regular contact with researchers, either through staff seminars or written communication, and in-house commitment to accuracy. Other than the seminars we have given for them, and the course we offered in 2000, all training is done in-house (T. Sonal, Whale Watch™ Kaikoura Ltd, pers. comm.). It may be helpful to design a framework for co-operative exchange of information between the whale watch industry, scientists and DOC.

Wings over Whales hands out a brochure at the end of the flight, providing some information on the company and the sperm whales. No such material is given out on Whale Watch's tours. Another option could be to present posters, videos or interactive educational materials in the public area. This would allow tourists to learn about topics which are of interest to them at their own pace. Furthermore, it would give tourists whose first language is not English an opportunity to learn more easily.

The educational content of eco-tourism is, in large measure, what sets it apart from thrill-seeking tourist ventures, such as bungy-jumping. Impact of whale watching on whales can more easily be justified if educational benefits are maximised. The educational content of the whale watching experience at Kaikoura could be significantly increased by simple and cost-effective means.

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