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# WHALE RESPONSES TO ANTHROPOGENIC SOUNDS: A LITERATURE REVIEW

by

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**WHALE RESPONSES TO ANTHROPOGENIC SOUNDS:
A LITERATURE REVIEW**

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**ABSTRACT**

Odontocete (toothed) whales, such as the sperm whale, depend upon sound for communication and for environmental information. Their acoustic abilities ensure that whales hear and respond to many of the sounds introduced by humans into the marine environment. Particular concern has arisen that the growing interest in viewing whales up close -"whalewatching" -will cause disturbance to individual whales and ultimately have a negative effect on whale populations. This report reviews the available evidence concerning the impacts of noise disturbance on cetaceans, including the mysticete (baleen) whales as well as the odontocetes. It is suggested that from a perspective the most important matter to consider is whether whalewatching reduces the size or biological fitness of whale populations. Thus, a recommended approach for managing whalewatch operations is to combine commonsense regulations with a program of population-level monitoring. Photoidentification and acoustic methods are adequate for developing a population profile. Radio-tagging of sperm whales has yet to be attempted but would provide important supplementary information on behavior and habitat use.

## 1 INTRODUCTION

Since the early 1970s, as commercial whaling has declined, more and more people have become concerned about the impacts on whales of human activities other than whaling. Apart from the obvious dangers of environmental contamination and non-deliberate capture in fishing gear, what effects do such activities as shipping, boating, military maneuvering, seismic testing, offshore drilling, and other industrial or recreational operations have on cetaceans? Reliant as they are upon sound for communication, prey detection, and orientation, the cetaceans, and particularly the acoustically sophisticated odontocetes (toothed cetaceans), would seem to be especially to disturbance from underwater noise.

Considerable effort has been devoted to studying the actual and potential effects of

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anthropogenic (human-caused) sounds on cetaceans. Researchers have studied whale responses to tour boats ("whalewatching" traffic), aircraft ovefflights, transport vessels, underwater seismic pulses, drilling noise, and, most recently, the low-frequency "hums" projected underwater to help measure global warming (the Heard Island feasibility test; Acoustic Measures of Global Ocean Climate, AMGOC). Some experimental work has been done with cetaceans under controlled conditions in captivity. Underwater broadcasts ("playbacks") of various kinds of sound have been used in laboratory and field studies to evaluate whale responses. Observations of wild whales under "normal" (presumably undisturbed) conditions have been compared with observations made in the presence of various stimuli, such as industrial operations or approaches by vessels. In rare instances, investigators working with wild cetaceans have been able to control the nature and timing of the animals' exposure to certain kinds of sound. More often, these at-sea observations have had to be opportunistic and ad hoc, leading to ambiguous results.

Most studies of whale responses to disturbance have been conducted in North America, and they have involved, primarily, the large baleen whales (humpback, bowhead, gray, and right) or the small to medium-sized toothed whales, including the beluga, the narwhal, and some dolphins.[2] Relatively little direct attention has been given to the effects of disturbance on the largest toothed whale, the sperm whale. However, considerable effort has been applied to studying the acoustic behaviour of this species, and during the past decade field techniques have been developed for studying the sperm whale's social organization, reproduction, and feeding behaviour. Research on sperm whales has been driven by sheer scientific curiosity as well as the practical need for information with which to manage their exploitation. In much of the world, sperm whales occur in deep water far shore. Thus, they tend to be less exposed to nearshore human activities than are the balaenids (right whales), balaenopterids (rorquals), and gray whales that make regular coastal migrations or enter shallow embayments. Another relevant difference is that sperm whales, even when they are present close to shore, make very long, deep dives in comparison with those made by the mysticete (baleen) whales. Such behaviour makes sperm whales challenging research subjects, particularly if one is trying to monitor the activities of an individual in order to evaluate its responses to disturbance.

The nearshore intrusion of deep water along the northeastern coast of the South Island, New Zealand, the southwestern portion of the former Cook Strait whaling grounds, provides exceptional opportunities for observing sperm whales (Gaskin 1971, 1973, Dawson 1985). The whalewatching enterprise that has developed at Kaikoura in recent years (e.g. Hides 1991) is among the few such operations in the world for which the sperm whale is a principal attraction. The present review of literature has been undertaken to provide background for the Department of in its evaluation of the need to regulate the whalewatching industry near Kaikoura.

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[2] **See Appendix 1 for a list of vernacular and scientific names of the species mentioned in the text of this report.**

## 2 PERSPECTIVE: SHORT-TERM (INDIVIDUAL) AND LONG-TERM (POPULATION) EFFECTS OF HARASSMENT

Richardson *et al*. (1991a) provided a comprehensive review of the effects of noise on marine mammals. Their analysis shows the complexity of the issues involved as well as the difficulty of obtaining conclusive empirical evidence. For example, individuals of the same species have shown varying sensitivity to a particular noise. This apparent variability in responsiveness could be due to: (a) physical factors such as the characteristics of the noise in question, its attenuation rate, and the background noise level; (b) real differences in sensitivity between individuals, or in the sensitivity of the same individual at different times; or (c) differences in activity (e.g. resting, feeding, socializing), age and sex, habitat, or degree of habituation. Richardson et 334; also see and Donovan 1986) cautioned:

> This variability in sensitivity makes it difficult to define criteria of responsive-ness, and has led to seemingly conflicting evidence about sensitivity to particular types of noise. Large sample sizes are needed in order to characterize the range of variation in sensitivity. Careful attention must be given to the situation in which each observation was collected. Even when the circumstances of the observations are well defined or controlled, there will be inherent individual variation in sensitivity. No single criterion of responsiveness will apply to every individual even within a defined situation.

One broad-scale study suggested that vessel traffic significantly decreased the probability of sighting a "squid-eating cetacean" (11 odontocete groups, including the sperm whale) but had no apparent effect on the probability of sighting a "fish-eating cetacean" (three mysticete and five odontocete species) (Sorensen *et al* 1984).

Duffus and Dearden (1992) have developed a useful matrix showing immediate, short-term, and long-term consequences of direct (mainly behavioural) and indirect (mainly ecological or population) impacts of disturbance on whales. They also attempted to evaluate whalewatching in terms, with, for example, the impact of tourism on the whales viewed as a cost weighed against various economic and non-economic benefits. For simplicity in the present context, it is suggested that all or most of the effects of disturbance can be classed as either short-or long-term. No attempt is made here to identify or evaluate the benefits of whalewatching, although it is recognized that these should be taken into account in any comprehensive analysis of net impacts.

Short-term effects are what can be readily seen and measured. Individual animals or, in some situations, herds, flocks, schools, or pods, respond to a stimulus by changing their behavior. A whale dives abruptly as a helicopter flies overhead; a pod of dolphins scatters as a motor boat approaches. Such observable, proximate responses to anthropogenic sounds provide only limited information about the consequences of disturbance. They demonstrate the animals' sensitivity to acoustic stimuli certain kinds of sound bother them. However, it is unlikely that occasional makes much difference to an animal's biological fitness, although this may depend on its age, reproductive state, and general health status. Repeated or cumulative exposure to short-term stress could have more far-reaching consequences.

The long-term effects of exposure to stressful circumstances are less obvious and much harder to measure than the immediate behavioral responses to specific disturbances. Long-term effects can be manifest at the individual or the population level. For example, intense sounds can cause structural damage to the ears of individual animals. Repeated episodes of interrupted foraging and flight may cause an energy deficit and thus compromise the whale's general health status. Chronic physiological stress can cause hormonal changes that lead to lowered resistance to disease, increased susceptibility to natural environmental perturbations, or poor reproductive performance (e.g. Majors and Myrick 1990, 1991; Harlow *et al.* 1992). For the population as a whole, the aggregate effect could be a lower recruitment rate or a decline in life expectancy that results in population decline. However, even if such trends can he demonstrated, it may be virtually impossible to ascribe the cause solely to harassment. Natural and anthropogenic changes in the animals' environment, reduced plane of nutrition, disease, natural demographic variability, deliberate or accidental killing in hunts or fisheries, and other factors may all need to be considered as potentially contributing causes. Long-term studies that address the ultimate effects of disturbance are usually confounded by the problem of identifying actual causal factors from a set of possibilities.

Repeated exposure to aversive stimuli may lead to tolerance and, eventually, habituation by the animals. Such tolerance seems to develop more often or more rapidly in situations where the stimulus, however loud or otherwise disruptive it may be, is predictable. For example, it is often said that whales respond less strongly to the activities of working fishing vessels than to those of tour boats or research craft. Fishing can be routine work, and its associated sounds may become essentially part of the whales' "natural" ambient acoustical environment. In contrast, close approaches by whalewatching and research vessels can be experienced by the whales as novel and unpredictable events. The sounds associated with such activities may be startling and intrusive compared with fishing-related noise. Even if some degree of accommodation occurs, however, it is necessary to consider whether there is a threshold of cumulative exposures which, once reached, causes cetaceans to abandon traditional congregating sites or routes of migration. It is also important to bear in mind that tameness in wild animals may not be entirely beneficial. For example, ship collisions are a major cause of right whale mortality off the eastern United States (Kraus 1990), and increased habituation to vessels could make the animals even more susceptible to collisions (Kraus 1989; S.D. Kraus, pers. comm. March 1992).

## 3 ORGANIZATION OF THIS REPORT

Many of the studies reviewed here focus on a single species or a group of closely associated or closely related species (e.g. beluga and narwhal, both in the family Monodontidae). Thus the main body of the report is organized on a species basis. Within each species or species-group section, the discussion is sometimes subdivided by subject, such as the effects of aircraft noise, boat engine noise, sonar, etc. **A** few studies have a more topical orientation and refer to the effects of particular types of disturbance on cetaceans generally or on taxonomically diverse groups such as arctic cetaceans. Some of these studies are themselves literature reviews. Their findings have been integrated with the species sections or mentioned in the last few sections devoted to subjects that are not species-or group-specific.

# 4 SYSTEMATIC ACCOUNTS BY SPECIES OR SPECIES-GROUP

## 4.1 Mysticete (Baleen) Whales

### 4.1.1 Gray Whale

**The coastal migration corridor:** Whalewatching tourism may have begun as early as 1960, by which time people in southern California were watching gray whales from excursion vessels (Wilke and Fiscus 1961). By the mid 1960s there was concern that the coastal migration route of the gray whales was being abandoned in favour of an offshore route, and increasingly heavy small-boat traffic near shore was cited as one possible cause (Rice 1965). Later it was claimed that "increasing boat traffic was causing even greater numbers [of gray whales] to migrate far offshore" (Wolman and Rice 1979: 276; also see Food and Agriculture Organization 1978: 13). However, these positive statements were not supported by much direct evidence (Wolfson 1977, Reeves 1977). Bursk (1989) noted that although the technology for finding whales had improved (e.g. spotter aircraft were used) and the gray whale population was increasing, fewer whales were being seen on whalewatching trips off southern California during the late 1980s. He implied that harassment, mainly by "recreational boats" as distinct from commercial whalewatching vessels, had driven the whales offshore and thus caused a decline in the encounter rate near shore. In a study of the behaviour of migrating gray whales in the presence of vessels, Bursk (no date) identified close approaches by privately-operated power boats ("skiffs") as the primary cause of major changes in the whales' swimming direction. He also described "snorkeling" by gray whales as an adaptive response to boat harrassment[3]. The percentage of the gray whale population using the coastal migration route off southern California declined from 18% in 1988 to 15% in 1989 and 12% in 1990 (Sumich and Show 1990).

Migrating gray whales off California were exposed to offshore seismic and drilling noises broadcast underwater to test their reactions (Malme *et al.* 1983, 1984). In the case of airgun blasts, the whales consistently deflected their swimming course to increase separation distance from the sound source only when received levels were at least 160-170 decibels (referenced to 1 micropascal at 1 m). They sometimes tolerated surprisingly strong intermittent noise pulses during the seismic playbacks. Responses to continuous drilling noise generally began when received levels reached approximately 120 decibels.

**The wintering lagoons**: It was claimed during the 1970s that the commercial cruise boats taking people into the gray whale's Mexican nursery lagoons were causing "considerable harassment" (Wolman and Rice 1979: 278-9). Dramatic apparent changes in lagoon occupation by gray whales from the early 1950s to early 1970s were interpreted as evidence that the whales had been greatly disturbed by barge traffic (related to evaporative saltworks along the shores of the lagoons) and tourist activity (Gard 1974). Scientists and naturalists expressed strong opinions about the impacts of tourism on the gray whale population (American Society of Mammalogists 1971, 1972, Brownell 1977,

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[3] **Bursk (no date) uses "snorkeling" to refer to the times when gray whales expose only the blowholes upon surfacing to breathe.**

Reeves 1977) and these led eventually to the partial closure of one major nursery lagoon de Liebre, or Scammon's) and to restrictions on access to another (San Ignacio) (Jones and Swartz 1984). However, apart from Gard's (1974) retrospective analysis of trends in lagoon usage, no systematic attempt was made to assess the impact of tourism on gray whales until 1977.

In 1977 the U.S. Marine Mammal Commission initiated a two-year study at San Ignacio Lagoon for the express purpose of documenting and evaluating the effects of vessel traffic on gray whales (Swartz and Cummings 1978, Swartz and Jones 1978). Whale responses to approaches by small boats diminished as the season progressed, suggesting increased tolerance or habituation. Responses were also influenced by the speed of approach and the whales' activity at the time of the approach. "Sleeping" or resting whales, for example, were far more sensitive to disturbance than were "courting" whales (Swartz and Jones 1978: 21). The whales generally avoided commercial fishing boats.

The study by Swartz and Jones continued for five years (1978-82) and resulted in substantial documentation of vessel activity, whale occupancy, and whale behavior in San Ignacio Lagoon. Their analysis led Jones and Swartz (1984: 365; also see Jones 1985) to conclude:

> ... none of the adverse consequences that we proposed might result from exposure to human activities were substantiated. Rather, ow findings to date suggest that the gray whales possess sufficient resiliency to tolerate the physical presence and activities of whale-watching vessels and skiffs and the noise produced by this level of activity without major disruption.

Gray whale use of San Ignacio Lagoon did not decline. In fact, the number of mothers with calves increased at a rate of approximately 10% per year from 1978 to 1982. The authors cited three factors that may have contributed to their unexpected results: (1) whale-watching skiffs were active only during the eight daylight hours, which meant that the whales were being left alone for two-thirds of each day; (2) skiff operators recognized that it was in their own interest to avoid disturbing the whales, so whales were generally approached slowly and respectfully; and (3) continued exposure to boat noise and whale-watching activity *"at the controlled level* observed during our study" (Jones and Swartz 1984: 366; emphasis added) may have led to habituation by the whales. Jones and Swartz (1984: 365) noted that the particular circumstances in the San Ignacio Lagoon study area may have affected their findings:

> We feel that a key factor responsible for maintaining the stability of the whale population in Laguna San Ignacio was the establishment of the gray whale refuge in the lagoon, which serves to regulate the number of vessels operating in the lagoon and provides an area free of all vessel activity as a sanctuary for the use of the whales (particularly females with calves)…

Gray whales in the wintering lagoons are less active acoustically than many other cetaceans; the functions of their sounds are unknown (Dahlheim *et al.* 1984). The exceptionally favourable conditions in San Ignacio Lagoon allowed Dahlheim (1987; also see Dahlheim and Fisher 1983) to conduct a variety of studies of gray whale responses to acoustic stimuli. Her work included attempts to correlate gray whale sound production with natural ambient conditions and with boat noise. She also conducted playback experiments involving the sounds of outboard engines, oil drilling, killer whales, gray whales, and test tones. In general, artificially increased noise levels caused increases in the gray whales' calling rate and changes in their call structure. The whales fell silent in response to killer whale calls and test tones broadcast underwater. In playback experiments, the level of whale response was strongly influenced by the manner in which the stimulus was presented. The rapid or sudden onset of a sound caused a more pronounced response than did the gradual introduction of a sound. An important conclusion of Dahlheim's study was that gray whales vary the structure and timing of their calls to avoid interference (e.g. masking) within their acoustic niche.

Aerial surveys of the major calving areas in 1980 led Rice *et al.* (1981: 486) to conclude that the data from previous censuses, including those used in Gard's (1974) analysis, were "inadequate for estimating population sizes and trends." There was much variation among the replicate counts conducted in 1980. A study of Negro Lagoon in the early 1980s indicated some year-to-year variation in lagoon use (Bryant *et al.* but probably not of a magnitude that would account for the changes in the 1960s and early 1970s described by Gard (1974).

It is often said to be preferable to approach whales with the motor idling or at slow speed than to approach them with no mechanical power. For example, according to (1983: "small boats with outboard motors are less disturbing to the [gray] whales [in winter nursery lagoons] than those crafts with no motor, since whales presumably can hear the motor and keep track of its location" (also see Dahlheim *et al.* 1984, Jones 1989).

**Effects of aircraft in the lagoons:** Although Mexican law requires that aircraft flying over Ojo de Liebre Lagoon during the season of gray whale occupation maintain an altitude of at least 500 m above sea level, aeroplanes have been observed to circle mothers and calves at altitudes of less than 75 m. "This type of harassment causes the animals to dive and occasionally leads to the separation of mother and young" (Withrow 1983: 13).

**Summary:** The report of the International Whaling Commission's (IWC's) special meeting on the assessment of gray whales in April 1990 (International Whaling Commission in press) summarizes the situation as follows (based largely on Moore and Clark [in press]):

> Evidence that vessel traffic causes [gray] whales to abandon an area is equivocal. Vessels in the breeding lagoons sometimes cause short-term flight reactions when moving at high speeds or erratically, with little response to slow moving or anchored vessels, and in some lagoons a tendency for whales to approach rather than flee vessels. Whale watching by recreational and craft, particularly off southern California, may negatively impact migrating gray whales by interrupting swimming patterns and thereby increasing energy consumption. Cumulative effects of offshore human activities are probably greatest in waters off southern California where an extremely concentrated human population focuses the combined negative effects on numerous offshore activities.

The report goes on to note that sensitivities to disturbance vary according to the whales' behavioral mode and the geographical context. Gray whales respond differently on their breeding and feeding grounds.

### 4.1.2 Humpback Whale

**Summering areas:** A qualitative change has been observed in the behaviour of humpback whales off New England (Watkins 1986, Beach and 1989). Whereas these whales generally moved away, reduced their surface activity, and became silent when approached by vessels in the 1950s, 1960s and early 1970s, their tolerance of vessels has greatly increased in recent years. Some individuals now exhibit strong positive reactions, interrupting their activities to approach and interact with vessels that slow nearby.

Humpback whales off southeastern Alaska are considered much less tolerant of marine traffic than are the whales off New England. Differing substrates (hard rocky basins off Alaska vs. open sand banks off Massachussetts) and degrees of exposure to vessels (light and infrequent off Alaska and heavy and frequent off New England) have been cited as possible explanations for the different sensitivities of the whales in the two areas (Beach and 1989).

Glacier Bay in southeastern Alaska has been the site of a long-running controversy concerning the sensitivity of humpback whales to ship disturbance. The bay was classified as a National Monument in 1925, and its status was "upgraded' to that of a National Park and Preserve in 1980 (Baker *et al.* 1988). In 1970 only four "large" ships (meaning mainly cruise ships but occasionally also meaning state ferries and military vessels) entered Glacier Bay. Seven years later, 103 large-ship entries were recorded by the National Park Service, and many additional visits were made by smaller tour vessels and private craft. A "sudden departure" of humpbacks from Glacier Bay was reported in the summer of 1978, and again the following year fewer whales entered and remained in the bay for the summer feeding season. This development led government agencies to commission studies to determine whether the whales had been driven away by disturbance (Johnson 1983).

A comparison of the acoustic environments in Glacier Bay and in Frederick Sound and Stephens Passage, where humpback numbers had increased during the time when their numbers had decreased in Glacier Bay, did not reveal sufficiently different acoustic characteristics to account for the major difference in whale density between the two areas (Malme *et al.* 1982, Miles and Malme 1983). Observations of whale and vessel interactions in both areas were made in 1981 and 1982, using shore-based tracking with theodolites supplemented by observations from a research vessel dedicated to the project (Baker *et al* 1982, 1983). The principal findings in 1981 were that: (1) increasing “obtrusiveness” of vessel approaches resulted in a decrease in the average interval between blows, an increase in total dive time, and an increase in maximum dive intervals; (2) other surface activities (excluding those related to respiration) did not provide a reliable measure of disturbance; and (3) decreasing separation distances between vessels and whales caused the whales to increase their swimming speeds, but a significant change in whale headings could not be demonstrated (Baker *et al.* 1982). Observations made from shore in 1982 led the investigators to suggest that the humpbacks in Stephens

Passage used two different strategies for avoiding vessels: (1) a “horizontal” strategy involving decreased dive times, longer blow intervals, and faster swimming when a vessel closed to within 2-4 km; and (2) a “vertical” strategy of increased dive times, decreased blow intervals, and slower swimming when a vessel approached to a distance of less than 2 km (Baker *et al.* 1983). *A* group of four humpbacks “chose to spend most of the summer feeding in the busiest, noisiest part of the [Glacier] Bay” (Johnson 1983). These whales displayed a strong sensitivity to vessel activities. The occurrence of aerial behaviour (e.g. breaching, slapping of the surface with the head, flippers, or flukes) was significantly correlated with the presence of large ships and with the closest point of approach by vessels. In one case it was possible to detect a close correlation between the onset of aerial behavior and sudden changes in underwater sound intensity caused by changes in engine speed and propeller pitch (Baker *et al.* 1983).

The work in 1981 and 1982 demonstrated "predictable short-term responses to vessel traffic" by humpbacks, but it did not prove that such responses were likely to "culminate in large-scale abandonment of a habitat" (Baker *et al.* 1988: 16). Changes in prey abundance and distribution are thought to have been implicated to some extent in the reduced use of Glacier Bay by humpbacks since 1978 (Baker *et al.* 1988, Richardson *et al.* and references therein). Regardless of the lack of conclusive evidence for large-scale, long-term effects, management agencies have taken measures to limit the numbers of vessels of various sizes and classes that can enter Glacier Bay in summer, imposed certain restrictions on vessels operating near whales, and banned the harvesting of humpback prey species. Allowance has been made in the regulations for incremental increases in vessel activity, in keeping with the results of an ongoing monitoring program.

The response of whales to vessels can be influenced by the properties of the water in a particular area. For example, Watkins and Goebel (1984) found that they could approach humpbacks closely (for tagging) when the boat and the whales remained on opposite sides of tidal current boundaries. Apparently the discontinuity in water masses served to reflect or refract sound at lower frequencies, making the whales unaware of the boat's presence until it moved into the same water, at which time the whales exhibited a strong startle response.

**Wintering** areas: Herman and Antinoja (1977: 83) expressed concern about the effects of tourist activity on humpback whales wintering in Hawaii:

> Increasingly, commercial and pleasure ships and small boats are launched to watch the whales, divers enter the water to observe, photograph, and perhaps touch the animals, planes and helicopters on tourist circle the animals. All of this unregulated activity constitutes a potential source of major harassment to the whales, and some controls on this activity are needed....

The report of a workshop held in 1977 to consider the problem concluded that whales in Hawaii "probably experience a great deal of harassment" (Norris and Reeves 1978: 10). It also cited an array of other human activities, possibly detrimental to humpbacks, that were occurring in Hawaiian coastal waters: for example, pollution, military and commercial traffic (including vessels and aircraft), and harbour development. Between 1977 and 1985 a consistent decline occurred in the percentage of observations of mothers with calves that were in nearshore waters (defined as within 0.4 km of shore) off the west side of Maui (Glockner-Ferrari and Ferrari 1985a, 1985b). This decline occurred in spite of constant or increased observational effort near shore. Glockner-Ferrari and Ferrari (1985b) cited reduced water clarity (due at least in part to agricultural runoff), heavier vessel traffic, and the proliferation of thrillcraft (e.g. parasails, jet skis, and ultralight aircraft) as factors possibly implicated in the changed whale distribution.

The rapid growth of whalewatching and other human activities in Hawaiian waters was reviewed recently by Forestell and (1990) and (1991). Beginning in 1985 the Hawaii Whalewatching Association established guidelines to be followed by boat operators on a voluntary basis. These included limiting the number of vessels near a group of whales to no more than three at a time, minimizing the time spent near mothers and calves, and controlling engine speeds when near whales. This regulation initiative was short-lived. Rather than advertising their affiliation with the Hawaii Whalewatching Association, most operators now claim to be associated with research organizations or conservation groups. Another recent development in Hawaii is the use of Zodiac-type inflatable craft for some excursions. The use of these moving vessels allows people to cover more water per unit of time and to reach new areas. Also, one operator rents inflatables to individuals so that they can embark on self-guided whalewatches. This development "is of particular concern because the renters are less likely to be aware of or to comply with applicable whalewatching guidelines" (Townsend 1991: 19).

Commercial whalewatching centered on humpbacks has developed recently in Western Australia (Perth) and Queensland (Hervey Bay). It has been reported that in the latter area near-term females "appear to respond at greater distances to boat noise than in other circumstances" (Australian National Parks and Wildlife Service 1991: 224).

### 4.1.3 Bowhead Whale

The bowhead whale, an arctic mysticete, has been the subject of intensive research over the past 15 years, partly because it continues to be hunted in spite of its depleted status and partly because it inhabits areas where substantial and alongshore industrial development has recently been completed or is under way.

**Seismic testing:** Alaskan Eskimo whale hunters and conservationists expressed concern about the impact on bowhead whales of seismic exploration in continental shelf waters off northern Alaska and the western Canadian Arctic during the late 1970s and early 1980s. This concern led the U.S. Minerals Management Service to sponsor studies to determine whether and to what degree seismic and other industry-related activities affect bowhead behavior (Reeves *et al.* 1984, Richardson *et al.* 1986, Ljungblad *et al.* 1988). Various approaches were used, involving differing degrees of experimental control. In all of the seismic studies, significant changes were detected in bowhead behaviour (mainly expressed in terms of surfacing characteristics and swim speeds and directions) under "disturbed" and "undisturbed" conditions. Whale responses to airgun blasts were most pronounced when the sound source was less than 5 km away, although avoidance began consistently at any distance less than 10 km. Whales returned to pre-disturbance behaviour within an hour after airgun activity stopped. The high-intensity, low-frequency airgun blasts were thought to be the principal causes of changed behavior, although it was recognized that in many instances the whales also may have been reacting to ship noise. Ljungblad *et al.* (1988: 193) suggested that the tendency of bowheads to reduce their submergence times during close exposure to seismic sounds could be related to the fact that received levels of airgun blasts are lower near the surface than at depth: "If seismic sound is irritating to the whales, one would expect the animals to spend more time where the sound is least intense [i.e. near the surface]." This is the "release effect" to which C.R. Greene, Jr., referred in Peterson (1981: 328).

Eskimo hunters strongly believe that seismic operations have caused bowheads to change their distribution during the autumn migration past Point Barrow, Alaska (International Whaling Commission 1987). Specifically, the hunters have argued that the whales now migrate farther offshore (Moore and Clarke 1992). An analysis of bowhead sightings made by aerial survey between 1982 and 1989 failed to demonstrate any statistically significant shift offshore. This result was not necessarily considered conclusive, however, since the shift could already have occurred between the late 1960s, when industrial operations related to oil and gas development began in the area, and the early 1980s. Also, the statistical test used (ANOVA) would not have detected a shift in annual mean distance from shore of less than 12 km, whereas a shift of less than 12 km could affect whaling success (Moore and Clarke 1992).

**Other types of industrial noise:** In a retrospective study similar in approach to that by Gard (1974) for gray whales (see 4.1.1, above), Richardson *et al.* (1987) compared the summer distribution of bowheads, based on detailed survey data from 1980-84 and limited data from 1976-79, with the distribution of industrial activity in the Canadian Beaufort Sea over the same period. They found pronounced year-to-year changes in bowhead distribution and considered two explanatory hypotheses: (1) that the cumulative effects of industry had led to avoidance, or (2) that whale distribution varied in response to "expected (but unproven) year-to-year changes in food supply." Richardson *et al* (1987) were unable to decide between the two hypotheses and noted that both factors could be involved. They felt that continued bowhead surveys and studies of zooplankton dynamics would be necessary for a definitive assessment. Hypothesis 1 would be disproven only if many bowheads returned to the main industrial area in a year with much industrial activity. Industrial activity declined in the Canadian Beaufort ea during the late 1980s, but in the absence of continued bowhead surveys it is not known whether use of the area by bowheads increased (Richardson *et al.* 1991a).

Bowheads in open water responded to broadcasts of recorded drilling and dredging noises by orienting away from the source when received levels and spectral characteristics were equivalent to what they would be within several kilometers of actual and dredges (Richardson *et al* 1990). In some of the playback tests, whales responded by decreasing their call rates, suspending their feeding behaviour, and possibly by changing their surfacing, respiration, and diving characteristics. It was suggested that individual whales exhibited differing degrees of sensitivity to these types of noise (Richardson *et al.* 1990). Experiments conducted in 1989 and 1990 involved playbacks to evaluate the short-term behavioural responses of bowheads (and belugas) to platform noise within the spring migration corridor off northern Alaska (Richardson *et al* 1991b). The bowheads responded consistently by changing their headings and swimming speeds when within 1 km of the sound source, and they exhibited subtle changes in surfacing and respiration cycles at distances as far as 2-4 km from the source. One limitation of these studies was that the projector used for the playbacks was unable to reproduce all of the low-frequency components of recorded industrial sounds. The researchers stressed the uncertainty of the biological significance of their results, noting that the effects were "localized and temporary." Although some migrating bowheads dove in response to close approaches by turbine-powered helicopters, others showed no obvious reaction to low overpasses (150 m or less).

### 4.1.4 Right Whales

In New England waters right whales are characterized as less noise-sensitive than fin whales and humpbacks. Nevertheless, three types of response by right whales were mentioned by Watkins (1986): slow but consistent movement away from passing ships; quick diving, often without raising the flukes, when disturbed; and falling silent when disturbed. Watkins also noted his impression that right whales in nearshore areas had become less vocal through time (1950s to 1980s).

In the lower Bay of Fundy and Nova Scotian shelf regions right whales oriented away from an approaching vessel initially but had essentially random headings at the end of observation periods. Kraus (1989; S.D. Kraus, pers. comm. March 1992) cautiously suggested that this finding could indicate some degree of habituation. He qualified the suggestion by noting that responses of right whales to boats are highly dependent on antecedent behaviour, age, and group size. Kraus also introduced a novel approach for estimating the population-level impact of human activities on right whales. He analyzed the reproductive outputs of females in relation to the known frequencies of their encounters with one particular research vessel. Using a small data set, Kraus concluded that there was no significant difference in the number of vessel encounters of whales that had three or more calves and those that had only one or two calves. Kraus pointed to the relative importance of ship collisions as a cause of mortality and warned that habituation to vessels could have undesirable, and largely unforeseen, consequences. Decreased wariness may please whalewatchers but ultimately increase the risk to the whales of accidental collisions.

Mate *et al.* (1992: 138-39) judged their tagging operations as "neither overtly stressful nor a significant health hazard for right whales." The individual whales showed variable responses. In 1989 one whale "resumed sleeping almost immediately after tagging," whereas two others showed a stronger avoidance response after tagging than would have been expected from untagged whales. The next year only "mild reactions" were observed from tagged right whales.

Garciarena (1988: 3) described Peninsula Valdes, Argentina, as an ideal site for a natural experiment: "…a group of animals subjected to a major tourist whalewatching industry, and a similar sized group of control animals, living in the relative quiet of a protected gulf." He pointed out that useful studies could be conducted from shore, thus eliminating the risk of having disturbances caused by the research vessel confound the results of the study. Although Garciarena (1988) states in his brief published report that the responses of right whales to approaches by boats depend on the type of group involved (e.g.

mother and calf, mating group, "subadults") and on the manner of approach, he provides no further details. Comparisons of the swimming speeds of whales in different portions of the study area have been interpreted to suggest that regular exposure to vessel traffic causes whales to swim faster than they would if left undisturbed (Alvarez Colombo *et al.* 1990; Payne and Rowntree 1992). Aerial surveys conducted annually from 1971 through 1990 along the shores of Peninsula suggest that the distribution of right whales has changed (Payne and Rowntree 1992). It appears as if the number of whales using the northern bay, which is a whale sanctuary, has remained constant. In contrast, fewer whales have been seen along the "relatively pristine" eastern outer coast, while a great many more whales have begun to occupy the "disturbed" southern bay, where whalewatching activity is most intense.

### 4.1.5 Minke Whale and Beaked Whale

Nishiwaki and Sasao (1977) attempted to demonstrate that a dramatic postwar increase in vessel traffic in Tokyo Bay and along the northern coast of Kyushu was at least one of the principal causes of a change in whale distribution. The catch of Baird's beaked whales[4] on the Boso whaling ground declined as the number of vessels entering Tokyo Bay increased. On the Yobiko whaling ground off Kyushu, the catch of minke whales also declined. Japanese whaling on the Yobiko ground stopped after 1957, apparently because too few minke whales were available. This study called attention to the problem of whale disturbance by vessel traffic, although the proposed cause-and-effect relationship was confounded, in this instance, by the probably colinear impact of whaling on the populations.

Minke whales that are not hunted often approach and exhibit curiosity toward vessels. After years of exposure to ship traffic, however, this type of behaviour may wane and be replaced by apparent indifference (Watkins 1986).

During studies of minke whale responses to sighting-survey ships in the Antarctic, helicopter overflights elicited the following types of "fright reactions" from whales: lobtailing followed by rapid changes of direction and high-speed swimming; convergence of a group of parallel-swimming individuals, followed by breaching and simultaneous diving; a quick start followed promptly by diving; and rapid acceleration to sustained high-speed, near-surface swimming (Leatherwood *et al.* 1982: 800). Although most of the whale responses to the aircraft were more subtle, involving only a change in course, rolling onto the side, or diving, "aversive reactions to the aircraft were not uncommon following the second to fourth pass overhead, particularly when altitude was reduced substantially" (Leatherwood *et al.* 1982: 798).

### 4.1.6 Fin Whale

Fin whales on the South Atlantic whaling grounds exhibited varying degrees of approachability (Gunther 1949). While actively feeding, the whales were relatively easy to approach. Gunther suggested that the whales' "mood" had an important bearing on their sensitivity to disturbance. Fin whales that were feeding or socially active "seemed

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[4] Baird's beaked whale is the largest member of the family Ziphiidae. It is in some respects ecologically similar to the sperm whale.

to take little notice" of the presence of a research vessel (Watkins 1981b: 89). In the Gulf of St. Lawrence Ray *et al.* (1978) found fin whales difficult to approach for tagging. The animals changed direction underwater, members of groups occasionally parted company, and their ventilation cycle was irregular, making it hard to predict when they would surface.

Off Cape Cod in the western North Atlantic, fin whales were considered the most "wary" of the local cetaceans during the 1950s to mid 1970s (Watkins 1986: 258). They appeared to react strongly to low-frequency ship noise that was in the frequency range of their own sound production (15-100 Hz). The fin whale's characteristic 20-Hz signal is apparently sometimes "stimulated by such a disturbance as a noisy ship, and sometimes the signal will cease after the arrival of a ship" (Schevill *et al.* 1964: 148). It was long considered impossible to study fin whales because of their inapproachability. However, since the mid 1970s, the fin whales near Cape Cod have become much less wary. They now tend to ignore vessels and rarely change their swimming course at separation distances greater than 30 m, but they continue to fall silent when an operating vessel is nearby (Watkins 1986).

The sensitivity of fin whales to disturbance from an aircraft is lessened if the craft is kept off to the side and downwind and if its shadow does not pass directly over the animals (Watkins 1981b).

## 4.2 Odontocete (Toothed) Whales Other Than the Sperm Whale

### 4.2.1 Killer Whale

Killer whales in Johnstone Strait, British Columbia, have been the focus of a rapidly growing tourist industry since 1980 (Duffus abd Dearden 1992). The effects of whalewatching boats on these whales were studied in 1983 using a theodolite to track whales and boats from a stationary, elevated position on shore (Kruse 1991). Kruse compared the behaviour of whales under two conditions: disturbed (a vessel operating within 400 m) and undisturbed (no vessel operating within 400 m). The variables used to represent whale behaviour were cumulative swimming speed, milling index (reflecting the linearity of a whale's route between two points), and course bearing. Kruse found that the killer whales consistently increased their swimming speed and swam toward open water as vessels approached. The strait is only 3.3 to 6.4 km wide at the study site. When disturbed, the whales in Johnstone Strait generally moved into the more open waters of adjacent Queen Charlotte Strait, suggesting that the greater freedom of movement in open water allowed the whales to avoid boat disturbance. Kruse’s data failed to demonstrate significantly different responses to large (longer than 7 m) vs. small (shorter than 7 m) vessels, or to vessels powered by outboard vs. inboard engines. Also, she found no significant difference in the milling index of undisturbed vs. disturbed whales and concluded that the whales did not change course radically when approached by boats.

Additional studies were carried out in Johnstone Strait in the summers of 1987 and 1989 to assess the impact of human activities on killer whales using "rubbing beaches" within the Robson Bight Ecological administered by the British Columbia Ministry of Parks

(Briggs 1988, 1991)[5]. Observers were sequestered in blinds to ensure that their presence did not affect whale behaviour. They monitored whale activity around the clock (24 hours per day, with the aid of a hydrophone at night) and vessel activity mainly during the daylight hours. The results showed unequivocally that killer whales responded to approaches by vessels to within 300 m, either by leaving the area, by rubbing for shorter periods than normal, or by spending less time than usual inside the reserve. Landings by people on shore always caused the whales to leave the area. The short-term effects on killer whales in this area seem reasonably clear: the animals are extremely sensitive to the presence of people. Long-term, or population, effects are less certain, but the evidence suggests that the whales' use of the rubbing beaches has decreased as the level of human activity nearby has increased (Briggs 1991).

On one occasion in the western Indian Ocean a whaling catcher boat (640 tons) was closely approached and surrounded by a pod of 11 killer whales. During 45 minutes of observation, three members of the pod, including the two adult males, were marked with "Discovery" type tags. The whales showed no sign of a response, apart from continued curiosity. As Lockyer (1979) commented:

> The lack of reaction to the marking rather surprised us because the mark penetrates the back blubber and underlying flesh. The large male, in particular, remained unperturbed and continued his close scrutiny of us alongside the vessel, as if nothing had hit him at all.

In Alaska, where killer whales damage fish caught on commercial longlines, deliberate harassment of the whales has been attempted (Dahlheim 1988). Tried approaches have included chasing them with skiffs, deploying sonic devices, and masking the sounds thought to attract the whales to the longlining vessels.

### 4.2.2 Beluga and Narwhal

**Deliberate harassment:** In Bristol Bay, Alaska, a number of attempts have been made to drive belugas away from rivers where they were preying on outmigrating red salmon smolt. Methods used have included harassment with motorboats and small dynamite charges as well as the broadcasting of killer whale sounds underwater. This "beluga spooker" program was discontinued after 1978 (Frost *et al.* 1984).

**Industrial ship traffic:** Much concern has been expressed about the effects of industrial traffic on arctic and subarctic cetaceans. Some of this concern has arisen from the peculiar environmental conditions under which vessel-whale interactions take place in high latitudes. Both narwhals and belugas are closely associated with sea ice during much of the year. Although both species are capable of surviving in extremely harsh conditions, the natural processes of ice formation and movement sometimes lead to ice entrapment and death from starvation or suffocation as well as facilitated predation by polar bears and human hunters. Stirling and Calvert (1983) noted that artificial passages and openings

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[5] Killer whales visit beaches during the summer, apparently to rub against the pebbly substrate (see Hoyt 1990)

in the ice created by icebreakers could lead to more frequent whale entrapments. They also cited the work of Møhl (1980) who, extrapolating from data on World War II cruisers, calculated that a tanker passing within 100 m of a seal or whale could seriously impair or entirely mask the animal's communication sounds. Møhl (1980) further suggested that the noise produced by liquified natural gas (LNG) tankers could cause hearing damage and nausea to marine mammals.

Mansfield (1983) reviewed the theoretical potentials for masking of sounds, physiological impairment of hearing and balance, and changes in the behaviour and productivity of arctic whale populations caused by continued exposure to the sounds of LNG tankers (also see Peterson 1981). At the time of Mansfield's review, the main body of empirical data on beluga responses to disturbance consisted of a series of unpublished reports by consulting companies working in the Beaufort Sea, where beluga distribution, relative abundance, and behaviour had been monitored annually since 1972. This work suggested that belugas could detect the sounds of vessels at distances of 3 km (based on audiograms) and that they would respond by moving away when a vessel closed to within 2.4 km (Fraker 1977 as summarized by Tillman and Donovan 1986: 28).

Experiments using underwater playbacks of the sounds of offshore drilling operations and transport vessels, and observations of responses to local boat and aircraft activities, showed that wild belugas in Bristol Bay, Alaska, "respond more negatively to sudden changes in sound level than to sustained sounds" (Awbrey and Stewart 1983; also see Stewart *et al.* 1982). The belugas tended to form larger groups and to increase their ventilation rates in response to vessel disturbance.

No empirical data on narwhal responses to disturbance were available as of 1983, although Mansfield (1983: 36) cited claims by hunters that large numbers of narwhals had been displaced from their normal summering areas in two years by the activities of an ore carrier.

The most nearly definitive work on beluga and narwhal responses to industrial noise is that done by Finley *et al.* (1990; also Finley 1990) in Lancaster Sound in 1982-84. These researchers used a combination of water-level from the ice edge, underwater acoustic monitoring, and fixed-wing overflights to evaluate whale responses to approaches by icebreakers and to icebreaking activity. The two species, in spite of their presumed phylogenetic affinity and partial sympatry, responded to these stimuli in remarkably different ways. As characterized by Finley *et al.* (1990: 112) belugas exhibited a "flee" response involving: rapid movement; herd formation and loss of pod integrity; asynchronous, shallow diving; a pagophilic, littoral orientation; and "alarm" calls. In contrast, narwhals exhibited a "freeze" response involving: slow movement or no movement; no herd formation but rather pod cohesion and body contact ("huddling"); submergence; a pagophilic, pelagic orientation; and silence. Finley *et al.* found that wild belugas became aware of and responded to approaching ships at distances much greater than predicted from calculations based on auditory thresholds estimated for belugas in captivity and on received ship-noise levels measured in the field. They cautioned that the disparity between their field observations and theoretical calculations could be due to the inappropriate application of laboratory audiograms to natural situations (cf. Watkins 1980b).

The short pulsed sounds ("clicks") of narwhals, produced at repetition rates of up to 300 per second and in narrow frequency bands, have been likened to the strings of clicks produced by sperm whales (Watkins *et al.* 1971). Such types of sound are generally considered communicative in function rather than for echoranging. Watkins *et al.* (1971) hinted that the clicks of narwhals might contain signature information, as do the stereotyped, repetitive click sequences ("codas") of sperm whales (Backus and Schevill 1966, Watkins 1977), and this line of reasoning was pursued by Ford and Fisher (1978) who had a larger sample of narwhal sounds to analyze. At the Lancaster Sound ice edge, Finley *et al.* (1990) found that narwhals sometimes made click signals exclusively rather than their usual mixture of clicks and pulsed-tone calls. These authors further noted:

> Like the sperm whale, the narwhal is a pelagic species and appears to be a deep diving teuthophage (squid-eater); such behavioural and habitat similarities might favour the development of similar acoustic behavior for maintenance of spatial organization.

Finley *et al.* (1990) interpreted the tendency of narwhals to fall silent in response to ship noise and rifle shots as an extension of their strategy for avoiding predation by whales. It is interesting that during a particularly well-documented series of attacks on sperm whales by killer whales, the sperm whales were silent immediately before the encounter and while trying to flee. Only while the killer whales were actually circling and closing in on the sperm whales did the latter emit "intense bursts of clicks," perhaps attempts "to assess the positions, orientations, and behaviour of the killer whales by echolocation" (Arnbom *et al.* 1987: 453). Sperm whales also react to underwater pingers by falling silent (Watkins and Schevill 1975; see section 4.3.6, below). Thus, sperm whales may stop producing sounds not only to avoid detection by killer whales but also to assess new or unfamiliar sounds in their environment.

**Drilling platform noise:** During a playback study focussed on bowhead whales, Richardson *et al.* (1991b) also made observations of spring-migrating belugas off northern Alaska. The belugas generally approached the sound source (which was projecting continuous noise recorded from a drilling platform) to within 200-400 m, then slowed down, milled, and in some cases reversed their heading temporarily. After several minutes of disruption, the whales continued their migration, with some of them passing as close as 50-100 m from the sound source. The investigators concluded that belugas have poor hearing sensitivity at the low sound frequencies involved in the playback experiments.

**Aircraft:** Observations of belugas in Bristol Bay, Alaska, suggested that the noise made by commercial or industrial aircraft caused relatively minor disturbance (Stewart *et al.* 1982). Aircraft engine noise penetrates the water only in a narrow band directly underneath the craft and therefore disturbs the animals below for no longer than a few seconds. It was suggested that disturbance could be eliminated or minimized by maintaining a flight altitude of at least 300 m and by avoiding flying directly over (i.e. within about 0.5 km of) the whales.

Groups of belugas migrating through pack ice in spring off northern Alaska showed variable responses to aircraft (Richardson *et al.* 1991b). Some appeared unaffected by low overpasses or by the near presence (within 100-200 m) of a helicopter standing on the ice edge with its engines running. Others responded by diving abruptly when aircraft flew overhead at altitudes as high as 460 m, or by doubling their separation distance from a helicopter standing on the ice edge.

### 4.2.3 Dolphins and Porpoises

Dolphins in populations that are exploited in various ways, for example in drive fisheries or in tuna purse seining, behave differently from dolphins in unexploited populations. Exploited dolphins are more inclined to avoid vessels than to approach or ignore them. "Running from vessels may constitute a significant proportion of the energy-consuming daily activity" of dolphins in the eastern tropical Pacific during the tuna fishing season (Food and Agriculture Organization 1978: 13). Presumably the animals recognize the "acoustic signatures" of capture vessels and, accordingly, respond to them by taking flight (Leatherwood and Platter 1975, Norris and Dohl 1980, Irvine *et al.* 1981).

Although motivated primarily by the need to assess bias in ship-board censuses of dolphins, a study by Au and Perryman (1982) provided useful insight concerning the animals' sensitivity and responses to ship noise. Schools of oceanic dolphins (genus Stenella) were from a helicopter as they were approached by a research vessel on the tuna fishing grounds in the eastern tropical Pacific. What Au and Perryman termed "radical, evasive manoeuvres," including bunching, compaction of relatively dispersed individuals and small subgroups, and ‘running’ (swimming fast, making long, flat leaps with considerable splashing) were regularly seen only after the ship closed to within 200 m of the school. However, as judged from relative motion plots and consecutive vectors of swimming speed and course, it was clear that the animals were already avoiding the ship at separation distances of 11 km or greater. According to K. Pryor (in Tillman and Donovan 1986: 28):

> ... *Stenella* spp. would react to tuna vessels at distances of 5-7 km: when a vessel drifted, porpoises oriented at random, but when engines were turned on, they moved away and this movement became even stronger as the vessel got underway.

"Seal bombs" (small, hand-thrown explosives) have been used in the tuna fishery to control dolphin movements during chasing, to prevent their escape through open parts of the seine during encirclement, and to guide or drive them from the net during encirclement (a procedure used to release dolphins). It is generally acknowledged that chronic or frequent exposure to the noises from tuna seiners, skiffs, and speedboats, as well as the impulse noise generated by seal bombs, is stressful and could have "long- term adverse effects" on the dolphins (Majors and Myrick 1990: 1). However, little work has been done to investigate the problem. Majors and (1990: 2) reviewed the literature for evidence of "audiogenic stress" in animals and expressed the hope that their review would "foster greater appreciation of the problem and also guide future studies of noise effects on dolphins" (also see Majors and Myrick 1991).

## 4.3 Sperm Whale

A substantial literature on sperm whale acoustic behavior has developed since 1966, when and Schevill provided the first thorough discussion of sperm whale clicks. Most of this literature has come from the early work of W.E. Schevill, W.A. Watkins, and associates (e.g. Watkins and Schevill 1975, 1977a, 1977b, Watkins 1977, Watkins *et al.* 1985, Moore and Watkins 1985) and the more recent work of H. Whitehead, J. Gordon, and associates (e.g. Whitehead and Gordon 1986, Whitehead 1987, 1989, 1990a, 1990b, Weilgart and Whitehead 1988, Mullins *et al.* 1988, Gordon 1987a, 1987b, 1991b). It is fair to say that the sounds of sperm whales are among the most intensively studied of those of any of the medium to large odontocetes. The documented acoustic repertoire of sperm whales is limited to various kinds of clicking; they do not produce high-frequency whistles as many dolphins do. The clicks of sperm whales are broad-band, with energy mainly between 200 Hz and 32 kHz. The question of whether or not sperm whales echolocate is somewhat controversial (see Backus and Schevill 1966, Norris and Harvey 1972, Watkins 1980a, Weilgart and Whitehead 1988, Mullins *et al.* 1988, Whitehead 1989, Gordon 1991a).

### 4.3.1 Response to Vessels

Observations of whale responses to whaling vessels, including catcher boats being used for whale marking, are probably of limited applicability for assessing responses to whalewatching vessels. As Gunther (1949: 135) commented with respect to fin whales, ... the view obtainable from the decks of a catcher might give rise to a wholly erroneous picture of the ways of the unmolested animal." Sperm whales in whaling areas are said to begin reacting to the approach of a vessel under power while still separated by a distance of nearly 15 km (Gambell 1968). When approached by a catcher boat, large groups tend to scatter and form small, closely-bunched groups, often heading in different directions. Small sperm whales may "pack closely together when frightened"; large individuals "frequently stay together during the early stages of the chase and only break up singly when their numbers are depleted, almost as if there might be some element of leadership involved" (Gambell 1968: 131). When chased, sperm whales off southern Africa dived as the vessel closed to within 300 m; they scattered in different directions underwater and resurfaced in smaller groups 1977). It should he noted, however, that the tendency of groups of sperm whales to scatter as they dive, then reconverge as they approach the surface, is typical, probably normal behavior (Watkins and Schevill 1977b).

Observations reported by Gaskin (1964) of sperm whales reacting to vessels provide no coherent or consistent impression. Travelling whales were said to "take little notice of an approaching boat, except to change course if it comes very close" (Gaskin 1964: 111). One group of whales made only shallow dives during the two hours of observation; while underwater they tried "to manoeuvre away from the launch" (Gaskin 1964: 112). Large solitary whales that had been feeding initially ran from the launch but then became stationary at the surface, hanging vertically head-up or rolled onto one side.

The musical term "coda" has been applied to the "characteristic repetitive temporal pulse patterns" that sometimes end the long click sequences made by sperm whales (Watkins and Schevill 19774: 1485). Codas are heard in specific situations, including times when a ship's engine starts or stops or when a noisy aircraft passes overhead (Watkins and Schevill 1977a). The sensitivity of sperm whales to sudden changes in engine noise is also manifest in their non-acoustic behaviour:

> The usual practice [while marking] was for the ship to idle waiting in the area until the whale's return to the surface was imminent and then to steer full ahead to meet the whale. As a result whales often were alarmed by the sudden surface engine noise, and plunged straight down again from a relatively shallow depth.... The turning point where the ascent halted and the whale descended again was usually between 50 m and 100 m. It is possible at this depth for the whale to see the course and movement of the ship as well as hear it (Lockyer 1977: 604).

Moore and Watkins (1985) noted that sperm whales in the North Atlantic were, at times, difficult to approach for close observation. "They appear, when engaged in certain behaviours or when a small calf is present, to be disturbed by a boat's presence." These authors also noted, however, that large calves have occasionally taken an interest in the research vessel and approached it closely. Papastavrou *et al.* (1989) reported that, during their efforts to approach and follow sperm whales in a 10-m auxiliary sloop off the Galapagos, they occasionally caused the whales to increase swim speed, dive prematurely, or change course.

**43.2 Response to Biopsy Darting**

The experiences of researchers attempting to obtain skin samples from sperm whales for molecular analyses of DNA provide some insight about the whales' sensitivity to disturbance. Reports on the responses of other large cetaceans to biopsy darting have been published but are not reviewed in detail here (e.g. Mathews *et al*. 1988, Brown *et al*. 1991, Weinrich *et al*. 1991).

Feeding sperm whales that were darted off Nova Scotia consistently showed a startle reaction, "suddenly flexing and turning their bodies and increasing their speed" (Whitehead *et al.* 1990: 320). Defecation sometimes accompanied the startle response (also see 1977). Some whales made deep dives (raised flukes and submergence for [apparently] 20-50 minutes) after startling; others made shallow dives (no flukes and submergence for 30-120 seconds). Those whales that did not immediately dive deep travelled significantly faster (4-7 km/h) than before startling (3-5 km/h) but this increase in swim speed lasted for only 2-3 minutes. One whale that apparently had not been making the typically deep feeding dives before being approached for darting startled, made a shallow dive, then remained near the surface and "appeared unaffected by the darting during the following 97 min of observation" (Whitehead *et al.* 1990: 321). Some of the sperm whales off Nova Scotia also startled at the approach of the vessel (a 10 m auxiliary sailing yacht) and seemed to respond to the sound of a missed biopsy dart striking the water. No significant post-darting change in surface time, exhalation rate, or dive time could be detected.

In a separate darting study off the Azores, involving a different type of dart, the feeding sperm whales exhibited broadly similar reactions. In addition, on one occasion a darted whale "rolled onto its back with its head slightly raised and showed its lower jaw, slightly agape above the water but without snapping it" (Whitehead *et al.* 1990: 321). This behaviour was interpreted as possibly a mild form of jaw-snapping (=jaw clapping), which Cardwell *et al.* (1966: 691) described as "characteristic of angry sperm whales." Also near the Azores, one startled whale that had made a shallow dive after being missed by the dart vomited. Whether the regurgitation of "bleached and semi-digested" squid was an indication of "severe disturbance" or was a regularly occurring, natural process is uncertain (Whitehead *et al.* 1990: 322). Several of the Azores whales showed a significant decrease in their exhalation rates after darting attempts.

Whitehead *et al.* (1990: 323) summarized the responses of sperm whales as follows: "Our data suggest that the whale's normal behaviour was interrupted for periods of up to a few minutes by the darting procedure but that there was no detectable change in behaviour due to darting over periods longer than this." In view of such short-term effects, Whitehead *et al.* (1990) expressed their intention not to use biopsy darts in future behavior studies of sperm whales. Instead, they apparently planned to rely for further sampling on sloughed skin found in the water near sperm whales.

### 43.3 Response to Implanted Tags

Two types of tag - one equipped with a sonar transponder for underwater tracking and one more conventionally equipped with a 30-MHz radio for in-air transmission during surfacings - were implanted on sperm whales in the Caribbean Sea (Watkins and Tyack 1991). The whales appeared to react forcefully to the sounds of tags striking the water (cf. Gaskin 1964) but did not appear disturbed by tag implantation per se. Nor was there any evidence that the whales responded to any of the sonar or telemetry signals emitted by the instruments.

### 43.4 Potential Masking of Sperm Whale Sounds

In evaluating the possible masking effects of underwater noise on marine mammals in the Arctic, Møhl (1981: 261) referred to "the information on size that sperm whales have coded into their multipulse clicks," citing Norris and Harvey (1972), Møhl *et al.* (1981), and Adler-Fenchel (1980). He considered this characteristic of sperm whale sounds "an example of a system in which any increase in noise reduces the confidence of the classification." None of the three sources cited by Møhl (1981) assessment of body size, which is the implication of his 1981 statement. Norris and Harvey (1972) proposed that the "burst pulses" of sperm whales function in echolocation and that the nature of the echoes received from different targets would allow at least gross assessment of target size.

Møhl *et al.* (1981), following another line of reasoning initiated by Norris and Harvey (1972), proposed the use of measurements of interpulse intervals in sperm whale clicks to estimate lengths of spermaceti organs, and in turn total body lengths, for populations of sperm whales. The validity of this method has been cast into doubt (Tillman an Donovan 1986: 34), but Gordon (1991b) demonstrated its potential usefulness.

### 43.5 Response to Sonar

Sonar[6] apparently was used in whaling for the first time soon after the Second World War (Mitchell *et al.* 1981; and 1982). Its use extended beyond merely allowing the catcher boat to close on a whale by tracking its underwater position (e.g. see Ash 1964: 64). Once whalers discovered that sonar caused a dramatic flight response from whales, a special "whale scarer” was developed in Norway. This device used six oscillators to generate ultrasonic pulses in three directions. The effect has been described as scaring the whale to the surface, "inducing panic and 'panting' and fatiguing the whale as quickly as possible" (Mitchell *et al,* 1981: 12). According to Tønnessen and Johnsen (1982: 251-2*n*) the whale scarer was especially effective on baleen whales, as it made them swim fast and near the surface. They were thus easier to see and tired more quickly. Sonar was used with sperm whales mainly to track lone, deep-diving individuals (cf. Lockyer 1977). "It is rarely used with schools of sperm whales as it tends to scatter them and make it difficult to catch a high proportion of animals from one school" (Tønnessen and Johnsen (1982: 252*n*).

Watkins (1977: 53) reported that echo sounders were of only limited use in tracking sperm whales underwater "because the whales reacted to the pulses, which probably modified their behaviour." During a cruise in the southeastern Caribbean Sea in November 1983, Watkins *et al.* (1985) observed that sperm whales were scattered, difficult to approach, and silent, contrary to the researchers' experience in the same area in other years. This unexpected and atypical behaviour was judged to be related to intense, local sonar signalling from military submarines operating in the area in conjunction with the invasion of Grenada by the United States:

> Immediately with the sonar sequences, whales that were subjected to the louder sounds became silent, and they often appeared to break off from their activities, scatter, and move away. The periods of silence apparently lasted longer in response to the higher level sonar signalling. Even after relatively less intense sequences, the whales were observed to be uncharacteristically timid and relatively quiet (Watkins *et al.* (1985).

The sonar signals were in the frequency range of 3.25 to 8.4 kHz. During a subsequent cruise to a nearby area in March 1984, the sperm whales were behaving as they had prior to November 1983. On the one occasion when a short sequence of military sonar was heard, the whales fell silent even though the signals were not high level. Sonars and calibration pingers operating at much higher frequencies (36-60 kHz) elicited no obvious response from the whales. Papastavrou *et al.* (1989) also reported that sperm whales did not react to a depth sounder that pinged at a frequency of 50 kHz.

### 4.3.6 Response to Calibration

Calibration pingers used for locating an array of hydrophones elicited clearcut responses from sperm whales (Watkins and Schevill 1975, Watkins 1977). These pingers generated sequences of at least six underwater pulses at a rate of about one per second, in the

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[6] The terms ASDIC and SONAR are acronyms for Anti-Submarine Development Investigation Committee and

for Sound Navigation and Ranging, respectively. They are essentially synonymous, but 'sonar' is used more frequently today.

frequency range of 6-13 kHz and with levels between +30 and +10 dB at 1 m re 1 dyne/cm$^2$. Observed responses were as follows:

> Nearby sperm whales reacted to the sounds of clicking for periods of 2 min or more. More distant whales fell silent for shorter periods. The level of the pinger sounds may have affected the response of the whales and therefore the duration of these silent periods. The animals did not appear to be frightened, but appeared instead to quiet, perhaps to listen. Only one of a group of nearby whales could **be** heard at one time. They departed at speeds of 2 knots or less, diving at less than a 15$^o$ angle, and they appeared to be going toward other whales clicking in the background (Watkins and Schevill 1975: 128-29).

### 4.3.7 Response to "Playbacks"

In a relatively crude experiment, Watkins *et al.* (1985) mimicked the sperm whale's "popular five-click coda" by hammering on a metal plate. The group of whales nearby responded by becoming silent and moving away from the area.

## 5 RESEARCH INVOLVING PASSIVE AND ACTIVE ACOUSTIC SYSTEMS, INSTRUMENTATION, AND TELEMETRY

Reviews of methods used to track cetaceans include those by Norris *et al.* (1974), Leatherwood and Evans (1979), Hobbs and Goebel (1982), Hobbs (1982), Irvine *et al.* (1982), Watkins (1982), Dietz (1986), Scott *et al.* (1990), and Wursig *et al.* (1990). Early attempts to track cetaceans with active acoustic (sonic) tags were by problems with the shortness of ranges obtained, the inadequacy of transducers, and the fact that the frequencies used for transmission fell within the hearing ranges of the research subjects (Leatherwood and Evans 1979). The use of radio beacons, either implanted in the blubber or strapped, harnessed, sutured, or bolted onto the bodies of cetaceans, quickly became the preferred approach (Watkins *et al.* 1980). For obvious reasons, different methods of attachment have been required for different-sized animals. The smaller and medium-sized cetaceans can often be captured and handled, then released after instrumentation, whereas telemetry devices generally need to be delivered to unrestrained large whales by shooting (e.g. with a bow, rifle, or shotgun) (Watkins and Schevill 1977c, Watkins *et al.* 1980, Hobbs and Goebel 1982, Swartz *et al.* 1987) or with a pole applicator (Mate *et al.* 1983). Some success has been achieved in efforts to track gray (Mate *et al.* 1983), fin (Ray *et al.* 1978; Watkins *et al.* 1984), Bryde's (Watkins *et al.* 1979), bowhead (Hobbs and Goebel 1982), and humpback whales (Watkins *et al.* 1981), using radio tags monitored from aircraft or ships. An attempt made in the late 1980s to track blue, fin, and humpback whales off California using dermal tags monitored from aircraft and shore (Swartz *et al.* 1989) was unsuccessful (S.L. Swartz, pers. comm., 11 May 1992).

Instrumented cetaceans have been observed to resume apparently normal associations with conspecifics and to engage in behaviour considered typical for their species (e.g. Ray *et al.* 1978, Leatherwood and Evans 1979, Watkins 1981a, Watkins *et al.* 1981, 1984, Hobbs and Goebel 1982, Mate 1989a, 1989b, Tillman and Donovan 1986, Scott *et al.*

1990, Martin and Smith 1992). Thus, at least in most instances, the application procedures and the carrying of the device do not seem to have caused serious disruptions in the animals' lives or to have compromised their fitness. Typically, the whales appear not to respond to the impact of the tag so much as to the manoeuvring of the vessel and to the sound of the tag striking the water.

Some of the benefits of satellite tracking of cetaceans are obvious, particularly for species, like the sperm whale, that live in wide-ranging populations (Rice 1989). Besides providing information on movements, satellite monitoring offers the potential for studying diving behaviour and habitat use. Considerable progress has been made in developing miniature, durable, saline-resistant packages that can be attached to large, free-ranging whales. To date, most of the benefits of satellite tracking and telemetry have been realized with pinnipeds (Stewart *et al.* 1989, DeLong and Stewart 1991, Heide-Jorgenesen *et al.* 192), dugongs (Marsh and Rathbun 1990), and small to medium-sized cetaceans (Tanaka 1987, Mate 1989a, 1989b, Martin and Smith 1992) rather than with the large whales. However, notable success has been achieved recently with right whales off eastern Noah America (Mate *et al,* 1992).

The U.S. National Marine Fisheries Service, Minerals Management Service, and Office of Naval Research jointly sponsored a cetacean tagging and tracking technology meeting in February 1992 to begin a coordinated development program. Unfortunately, the report of this meeting was not available at the time of writing. Once available, it should provide a good summary of state-of-the-art tagging and tracking technology.

## 6 THRESHOLDS AND RELATIVE FREQUENCY RESPONSES OF CETACEANS

Much work has been done since the Second World War on the acoustic behaviour and capabilities of cetaceans, particularly the smaller odontocetes that have been in captivity, thus making them available for experimentation. However, as recently as 1983 Ridgway and Carder (1983) observed that the sense of hearing had not been studied in the majority of cetacean species. Although the list of species for which audiograms are available has grown somewhat since 1983, it remains true that little progress has been made in testing the auditory thresholds and relative frequency responses of large cetaceans, including the sperm whale (S.H. Ridgway, in litt., 30 December 1991). The only significant data available as of January 1992 were the auditory brainstem response (ABR) waves recorded from a stranded neonatal sperm whale in Texas (Carder and Ridgway 1990). While in a large tank for (unsuccessful) rehabilitation, the whale was exposed to pulses ranging from 2.5 to 60 kHz. Its highest-amplitude responses were in the 5-20 kHz range; a weak response to 60 kHz pulses was observed. Overall, the waves of this young sperm whale were very similar to those observed in other odontocetes (cf. Ridgway *et al.* 1981). Moore and (1985) selected frequencies in the 40-60 kHz range for sonar tracking of sperm whales underwater: "These high frequencies were used because we believe them to be above the animals' hearing, and therefore would not disturb normal behaviour." Dahlheim and Ljungblad (1990) described a preliminary attempt to investigate the hearing capabilities of gray whales in the wild.

In the absence of experimentally-validated audiograms, it is generally considered reasonable to assume that a whale is, at the very least, sensitive to frequencies matching those of its own sounds. Much of the noise produced by large ships is at frequencies used in routine vocalizations by mysticetes, and considerable attention has been given to the potential problems for these whales, for example auditory interference by masking, displacement, and behavioural disruption (Richardson *et al.* 1991a). In contrast, the odontocetes, including the sperm whale, generally operate at higher frequencies than mysticetes, and thus they may not experience the same kinds of disturbance from low-frequency ship noise. However, relatively little empirical research has been done on small-boat noise (which has higher-frequency components) and its effect on odontocetes. The work with free-ranging belugas by Finley *et al.* (1990) showed that the use of audiograms from captive whales and theoretically-derived noise attenuation rates to estimate auditory thresholds and detection distances is ill-advised. There is no substitute for direct measurements made under field conditions.

## 7 CAPTURE STRESS

To my knowledge, there is no direct evidence for capture stress in cetaceans. However, the problem has been raised with respect to dolphins in the eastern tropical Pacific (Stuntz and Shay 1979). Some early observations of a "fear response" by spinner dolphins inside a tuna purse seine were reported by Perrin and Hunter (1972). Coe and Stuntz (1980) described two types of "passive" behaviour exhibited by spotted dolphins confined in tuna purse seines. Groups of five to 50 dolphins "rafted" at or near the surface, hanging tail down and showing no overt reactions to their surroundings. Such behaviour generally facilitated their release from the net during the backdown procedure. The other type of passive behaviour is that displayed by dolphins which sank well below the surface, tail-first, to lie for several minutes on the webbing of the purse seine, at depths of 2-3 m or sometimes as deep as 12-15 m. Coe and Stuntz (1980) considered two hypotheses to explain this passive behaviour. One was that it represents a "state of dearousal" similar to that of the Virginia opossum, which is often described as feigning death to deter predators. The other was that the dolphins' passive behaviour is equivalent to the documented physiological responses of some large terrestrial mammals which have been chased and captured, e.g. for zoos. Changes in blood serum enzyme levels can be used to detect such myopathies. Recently, some attention has been given to two other possible physiological indicators of artificial (i.e. human-caused) stress in dolphins: tissue resorption and replacement in permanent teeth caused by stress-induced hypocalcemia (Myrick 1988) and various changes in the adrenal glands caused by repeated episodes of chase, capture, and release (Majors and Myrick 1991).

At the IWC's 1982 workshop on whale behaviour in relation to management, the possibility was noted that "capture stress" could occur in whales that are chased repeatedly, as in whaling, but that the "occasional" chasing for tagging was less likely to be a problem (Tillman and Donovan 1986: 30).

High serum potassium levels found in dugongs that had been chased and drowned were interpreted as suggesting that these marine mammals are susceptible to capture stress, or capture myopathy (Marsh and Anderson 1983). Marsh and Anderson (1983: 2) viewed "pursuit by curious non-hunters" as well as deliberate chasing during hunts as potentially leading to capture stress in dugongs.

## 8 EVALUATION AND RECOMMENDATIONS

### 8.1 Overall Evaluation

A major frustration experienced by persons responsible for managing human activities around whales has been the lack of a single, readily observed activity or type of whale behaviour that could he construed as an unequivocal indication that the animal has been harassed. Even the trumpeting blows and tail slashes that sometimes characterize a response to disturbance are unreliable since these kinds of behaviour can be part of normal interactions among whales (Beach and 1989). It has also proven difficult to estimate a critical separation distance that should be maintained between vessels and whales. The natural variability in whale behaviour, the differences in sounds produced by vessels, and the variable sound propagation characteristics in different areas make generalized guidelines difficult to justify and enforce.

In a critique of the way the National Marine Fisheries Service has managed whale-watching in the United States, Tyack (1989) suggested that the agency had placed too much emphasis on individual and intentional "acts of harassment" which are relatively easy to monitor and document. In contrast, relatively little attention had been paid to the cumulative effects of human activities on whale populations. Whalewatchers may be "easy targets" for management, hut this does not necessarily mean that they deserve the disproportionate attention that they get from enforcement agencies.

It is clear from the work discussed in Section 4.3 that sperm whales react to novel acoustic stimuli by reducing or stopping their own sound emissions. Also, they respond by diving, changing course, and scattering when a vessel approaches rapidly or "aggressively." It is uncertain how additional documentation of short-term responses to various kinds of disturbance would benefit managers responsible for protecting sperm whales from harassment. There are good reasons for establishing guidelines or regulations for whalewatching, quite apart from the short-term, and possibly long-term, effects that irresponsible behaviour by vessel operators may have on the whales. These reasons have to do with the quality of experience for the passengers, respect for the rights of other whalewatchers, and attitudes toward wildlife generally. A recent workshop to review and evaluate aspects of whalewatching in the United States concluded that minimum approach distances, restrictions on activities such as swimming or diving with whales, and regulations related to how vessels approach whales were justified and desirable (Atkins and Swartz 1989a, 1989b). The workshop also stressed the need to take into consideration the nature of whale activities on the whalewatching grounds. An implicit assumption was the high importance of preventing disturbance to whales involved in calving or calf-rearing, mating, and feeding (perhaps in that order of priority).

## 8.2 Recommendations

The following recommendations reflect my personal sense of what information is needed to ascertain or predict the effects of disturbance on sperm whales off New Zealand and what approaches might be used to obtain such information:

1. From a perspective the primary goal of management should be to prevent deleterious long-term effects at the population level. The desirability of a sustained program of monitoring whale abundance, distribution, and behaviour in areas where whalewatching occurs is thus self-evident. Ideally, such a program would commence before the whalewatching enterprise begins to develop. The earlier a time series of data begins to accumulate, the better are the chances of detecting trends and establishing cause-and-effect relationships.

Because sperm whales spend more than half of their time below the surface and out of sight, censuses involving continuous movement by the survey platform (whether moving aircraft or slow-moving ship) invariably under-estimate population size. Particularly in view of the other kinds of information that can be obtained, I would recommend a small-vessel study of the kind used, for example, in the Galapagos (Whitehead *et al.* 1989, Arnbom and Whitehead 1989, Whitehead and Waters 1990) for estimating population size, delineating distribution, and defining the social organization and population structure of sperm whales off Kaikoura.

2. In evaluating the potential impact of disturbance, it is important to know something about the ways that whales are using the habitat in question. Are they simply passing through the area on migration? Are they coming there to feed or socialize? Are they remaining on the same grounds for extended periods (e.g. weeks or months at a time)? What age or sex classes predominate, and are the whales generally solitary or in groups? Perhaps most critical, are they using the area as a calving, calf-rearing (nursery), mating, or feeding ground?

These questions can be addressed to some degree by reference to literature from the whaling era (e.g. Gaskin 1964, 1968a, 1968b, 1970, 1971, 1972, 1973, Gaskin and Cawthorn 1967a, 1967b, 1973). However, the recent work of Whitehead, Gordon, Arnbom, and associates has demonstrated the feasibility of using "benign" (i.e. largely passive) techniques to obtain important insights about sperm whale behaviour, population composition and structure, and habitat use. A profile of the population of sperm whales off Kaikoura, developed from an eclectic but rigorous study such as those conducted in the northern Indian Ocean and near the Galapagos, would provide a valuable basis for judging the potential population-level effects of whalewatching.

3. A useful lesson from the recent satellite tracking of right whales off eastern Canada is that reliance solely upon passive techniques (photoidentification, acoustic monitoring, etc.) is insufficient for judging residency times. Right whales carrying satellite tags moved unexpectedly great distances in short periods:

> The return of several animals back into the BOF [Bay of Fundy] after extensive travel revises former assumptions regarding residency time. Previously, the time

> between repeat BOF sightings within the same season was considered an estimate of minimum residency time. Now it is obvious that animals can travel widely between such sightings (Mate et al. 1992: 137).

Strong arguments can be made for radio-tagging and tracking sperm whales. Particularly with satellite monitoring, the potential is great for learning about long-distance movement, speeds of travel, and relations to oceanographic phenomena such as currents and fronts (cf. Mate 1989a, 1989b). However, the problems of attachment and tag retention experienced with large mysticetes may be compounded in any attempt to radio-tag and track sperm whales (Watkins and Schevill 1977c). Not only do sperm whales have relatively thick, dense skin and blubber, but their proclivity for deep diving poses special challenges to pressure-sensitive equipment. Some further development work may be necessary before radio-tagging technology can be applied successfully to sperm whales (cf. Watkins and Tyack 1991).

4. Physiological monitoring, for example of an animal's heart rate, can be useful for assessing its responsiveness to aversive stimuli. Heart-rate monitoring of seals (by the Sea Mammal Research Unit in Cambridge, UK), and dolphins (by T. Williams in the USA) has been accomplished using tags, and a wire lead system for monitoring the heart rates of whales has been developed by K. Brennan and J. Lien at Memorial University, Newfoundland, Canada (Mate *et al.* 1992: 141). A complicating factor in interpreting heart-rate data from marine mammals is that they exhibit bradycardia (reduced heart rate) as part of a diving response. Thus, even if the remote monitoring of sperm whale heart rates were possible (and at present there is no proven technique for doing so), it may be difficult to distinguish normal changes in heart rate from changes due to a particular stimulus.

5. The potential value of whalewatching vessels as platforms for whale research has been exploited in some areas, particularly New England. Certain kinds of data, such as photographs for individual whale identification, can be collected at low cost from whalewatching vessels. It has been shown that sperm whales can be identified individually from photographs of the flukes (Arnbom 1987), and other valuable information on body size (= age class) and sex can be obtained from high-quality photographs showing particular features (e.g. Whitehead and Gordon 1986, Arnbom and Whitehead 1989, Whitehead and Waters 1990, Gordon 1990). By taking advantage of the time at sea provided by whalewatching vessels, and the volunteer assistance provided by whalewatchers and vessel crews, it should be possible to obtain much useful information on sperm whales off Kaikoura at low cost. It must be borne in mind, however, that photoidentification studies may involve some degree of harassment since it is necessary to position the vessel at a suitable angle and distance from the whale. Also, the need of whalewatching operators to follow timetables and cater to the interests of their passengers sharply limits the research options. The use of hydrophones on whalewatching vessels would enrich the experience for tourists, and the taping of sperm whale sounds might produce useful scientific data. Opportunities to sample whale feces and sloughed skin should not be overlooked. Properly preserved and documented specimens, however opportunistically they may have been obtained, can contribute to research.

Any initiative involving the use of whalewatching vessels as study platforms would need to have a training and coordinating component. For example, vessel operators would need to be instructed and equipped so that they were prepared to recover and preserve whale feces or sloughed skin. The specimens would then need to be curated and distributed to appropriate researchers for analysis. Several institutions in the United States have long performed these kinds of function in collaborative projects with commercial whalewatching operations: e.g. College of the Atlantic, Bar Harbour, Maine; the Center for Coastal Studies, Provincetown, Massachusetts; and the New England Aquarium, Boston, Massachusetts. In New Zealand, the Department of Conservation, the National Museum, or a university could appropriately take up such a role.

6. One obvious approach to assessing the potential short-term impacts of vessel traffic on whales in a particular area would be to characterize the sound spectra and intensities of the engines of vessels actually operating in the area, then to to compare these with the sounds known to be produced by the whales. Such a comparison would, if nothing else, provide a theoretical basis for predicting impacts.

7. The failure of whales to abandon an area of frequent disturbance cannot necessarily be taken to mean that they are unaffected, as implied by Payne (1978). The fact that they return annually to important feeding or calf-rearing areas where they were previously harassed by whaling can he interpreted, instead, as evidence that the animals have few or no alternatives (Brodie 1984). Richardson et al. (1991a: 331) cautioned that it is relevant, in considering the effects of a noisy human activity on marine mammals, to compare the "zone of acoustic influence" with the amount of "suitable" habitat available to the animals. Payne's (1978) suggestion of an experimental approach for testing the effects of whalewatching on humpbacks in Hawaii may be usefully adapted to the situation with sperm whales in New Zealand. He recommends that two areas that are "as similar as possible" be identified and that whalewatching be excluded in one and unrestricted in the other. Regular monitoring of whale usage of the two areas in successive years could lead to useful insights (cf. Payne and Rowntree 1992).

8. It has been suggested that airships offer many advantages for focussed studies of the interactions between whales and vessels (Hain 1991). This novel approach has not yet been applied anywhere on a large scale. However, it could be especially useful in situations where the whalewatching grounds are too far from shore for observations to be made from towers or cliffs yet are spatially and temporally well-defined. An airship could also be used to good effect in multi-platform studies, for example to supplement land-or boat-based observations.

9. Social-science research can play an important role in the management of "non-consumptive" human interactions with wildlife. The "potential benefits to conservation from the long-term effect of changing attitudes towards wild animals and natural habitats" (Duffus and Dearden 1990: 213) should be recognized and taken into account in any decision to restrict the growth and development of a whalewatching tourism enterprise. An evaluation of the economic and non-economic benefits of whalewatching to humans should he integrated with assessments of adverse impacts on individual whales or whale populations.

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## ADDENDUM

I became aware, literally as I was packaging the final report to send to Wellington, of the recent successful deployment of a new sonar tag in the West Indies. According to a short article in *Woods Hole Currents* 1(2) (spring 1992), W. A. Watkins has developed a sonar tag that is "essentially a transponder, a small tube of electronics that emits pulses of sound when electronically interrogated." Two of these sonar tags were tested on sperm whales in October 1991. The tags are expected to remain implanted in the whale's skin for "a few weeks" and provide data on "the direction, depth and distance of the whale from the ship." They are "thrown" from a ship or helicopter.

In view of this development, the Department of Conservation may wish to consider using these sonar tags to monitor some activities of the sperm whales on the whalewatching grounds.

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## Appendix I. List of vernacular and scientific names

Baird's beaked whale, *Berardius bairdii*

Beluga (White whale), *Delphinapterus leucas*

Blue whale, *Balaenoptera musculus*

Bowhead whale, Balaena mysticetus

Bryde's whale, *Balaenoptera edeni*

Dugong, *Dugong dugong*

Fin whale, *Balaenoptera physalus*

Gray whale, *Eschrichtius robustus*

Humpback whale, *Megaptera novaeangliae*

Killer whale (Orca), *Orcinus orca*

Minke whale, *Balaenoptera acutorostrata*

Narwhal, *Monodon monoceros*

Polar bear, *Ursus maritimus*

Red salmon, *Onchorynchus nerka*

Right whales, *Eubalaena* spp.

Sperm whale, *Physeter catadon* (= *macrocephalus*)

Spinner dolphin, *Stenella longirostris*

Spotted dolphin, *Stenella attenuata*

Virginia opossum, *Didelphis virginiana*