been awarded, consists of a comprehensive survey and analysis of relevant work in the world wide literature to date, using a computer-based system for data handling; the computer storage of the references permits easy duplication of the sorted indexes, and it is hoped that copies of the final version will be available to interested parties. Phase II of the project, for which the precise procedures will depend on the results and analysis of the data gathered in Phase I, is expected to involve direct experimental investigation of the intensity of traffic noise (derived on a statistical basis through automatic monitoring and processing procedures) at various high-density traffic locations across the country, together with a survey of attitudinal responses through various questionnaires and interviews on the effects of traffic noise on health. The principles of Phase II have been tentatively approved, and this part of the project is currently under negotiation with the Department.

The project is being carried out under the supervision of Professor J.E.K. Foreman, Director of the Laboratory; Dr. J.S. Bradley is coordinating the project assisted by Mr. M.A. Emmerson, a postgraduate student in the Department of Geography. The Laboratory's efforts will be complemented by resource personnel from other units in the University, in particular the Department of Psychology and the Faculty of Medicine.

WHALE ACOUSTICS

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INTRODUCTION

Four of the larger cetaceans have been found to emit "echolocation-type" sounds. These are one species of the suborder Odontoceti (toothed whales), the sperm whale *Physeter catodon* (Backus and Schevill, 1966) and three species of the suborder Mysticeti (baleen whales), the blue whale *Balaenoptera musculus* (Beamish and Mitchell, 1971), the Minke whale *Balaenoptera acutorostrata* (Beamish and Mitchell, 1973) and the Gray whale *Eschrichtius robustus* (Fish *et al*, 1974).

Five species of the family *Delphinidae* (smaller toothed whales often called dolphins and porpoises) have been demonstrated to use functional echolocation during experimentation with captive animals. These include the bottlenose dolphin *Tursiops truncatus*, the common porpoise *Phocaena phocaena*, the common dolphin *Delphinus delphis*, the striped dolphin *Lagenorhynchus obliquidens* and the Amazon River porpoise *Inia geoffrensis*. Evans (1973) presents a summary of the state of knowledge of echolocation by the small toothed whales.

ABSTRACTS OF RECENT DATA

Hydrophone arrays have been used to record repetative sound pulses of less than a few milliseconds duration from a fin, a humpback and a blue whale. The blue whale, temporarily entrapped by ice (Figure 1), emitted the acoustic signals into the water from the anterior portion of its 4 meter upper jaw. The front half of this jaw is devoid of air cavities and moving muscles, hence it is unlikely that the sounds are produced there. This data, therefore, suggests that the upper jaw is an acoustic wave guide. These signals, recorded on three hydrophones at ranges 5-10 meters from the animal, as well as signals from the free swimming fin whale, recorded at ranges 10-20 meters from the animal, indicate the following peculiar directional property of the sounds. The low frequencies are beamed forward, the higher frequencies to the sides.

DISCUSSION

According to a comprehensive review of echolocation in marine mammals by Norris (1969) "It is highly probable that echolocation in some form is widespread, if not universal, among odontocete cetaceans". It should not then be surprising that this excellent method of detecting food and other targets in the ocean could be employed by the baleen whales as well. Let us review the evidence.

a) Including the recordings mentioned in this paper, fourteen instances of short repetitive acoustic pulses (small target 'echolocation-type' pulses) recorded in the presence of baleen whales have been studied by twelve investigators (Painter, 1963; Wenz, 1964; Gales, 1966; Perkins, 1966; Asa-Dorian and Perkins, 1967; Poulter, 1968; Winn *et al*, 1970; Beamish and Mitchell, 1971; Beamish and Mitchell, 1973 and Fish *et al*, 1974). All of the investigators felt that the circumstantial evidence strongly indicated that the baleen whales (mysticetes) and not toothed whales (odontocetes) were the authors of these sounds. In three cases, that of a Bryde's whale reported in Beamish and Mitchell, 1973, that of the Gray Whale (Fish *et al*, 1974) and that of the fin whale reported in this paper, the evidence is exceptionally strong. In one case, that of the blue whale entrapped by the ice, the acoustic data as well as the experience of studying the animal with a stethoscope (Figure 2), indicated conclusively that the whale was the author of the recorded sounds.

b) Mysticetes make loud low frequency sounds as reviewed by Schevill (1964), Evans (1967), Norris (1969) and Payne and Webb (1971). These signals have adequate acoustic properties to produce substantial echos from the surface and bottom of the ocean, in fact Payne and McVay (1971) note that humpback sounds are "invariably followed by trains of echos". It would be naive to believe that mysticetes cannot hear these low frequency sounds or that when the echo returns from the surface that they do not use the signal to determine range (especially because the animal needs to reach the surface before the time arrives for its next breath). This is not proof of echolocation because it does not demonstrate the dependence of performance upon the acoustic signal but it is strong evidence suggesting echolocation.

c) Evans (1973) lists species of odontocetes that are now known to use echolocation. Of all aquatic animals, mysticetes are more similar in life style to odontocetes than to any other group of animals; in fact these two suborders are often observed communicating in terms of interactions of a social nature.

d) Mysticetes have middle and inner ear structures similar to those of odontocetes but substantially different from terrestial mammals (Fraser and Purves, 1960).

e) Many whalers have caused mysticetes to flee (presumably a fright reaction) in the presence of active sonar of the low ultrasonic frequencies.

The function of baleen whale sounds is not well known. Two possibilities are communication and "echointerpretation". However any cetacean sound may have more than a single function.

Echointerpretation is a method of learning about the characteristics of an object by analysing echoes from the object. Echo intensity which is a complicated function of output, transmission and target characteristics must be sufficient so that the echo can be recognized within the background ambient noise.

Once the echo is recognized the following information may be used.

a) pulse-echo time gives information about the range of the target.
b) echo direction together with pulse-echo time gives information about the location of the target, i.e. echolocation.
c) pulse-echo frequency shift gives information about the relative motion between the target and source.
d) repetitive echolocation also gives information about the relative motion between the target and source.
e) echo counting gives information about the density of the targets or biomass.
f) echo intensity gives information about target characteristics such as size, compressibility and density.
g) echo intensity and pulse-echo time may give information about the transmission medium characteristics.

Baleen whales are recalcitrant laboratory animals. Therefore it may be a long time before definitive experiments are performed to prove either their possible echolocation or the presence of higher orders of echointerpretation such as ability to measure zooplankton biomass. The usefulness of their evolved acoustic techniques to man can however be better and more quickly understood by means of definitive experimentation with man made active sonar. Let us therefore use the acoustic parameters of sounds recorded in the presence of cetaceans combined with the feeding and other behavioural characteristics of the animals to test acoustic echointerpretation techniques for quantitative zoogeographic studies of the oceans.

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Fig. 1 - Twenty-two meter Blue Whale temporarily entrapped by ice on the southwest coast of Newfoundland, March 21, 1974. The animal escaped before sunrise the following morning.

Fig. 2 - The use of a stethoscope to study heart beat and other acoustics of the live Blue Whale. The weight of the scientist had no observable effect on the behaviour of the animal.