

VARIATIONS IN VOCALIZATIONS OF FIN WHALES,
BALAENOPTERA PHYSALUS, IN THE ST. LAWRENCE RIVER

by

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Balaenoptera physalus, in the St. Lawrence River

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ABSTRACT

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Recordings were made of vocalizations from fin whales, Balaenoptera physalus from a fixed hydrophone in the St. Lawrence River between 28 June and 27 September 1979. Land-based observers monitored activity from a hillside hut while recordings were being made from a shoreline site. Photographs of dorsal fin variations were used to identify distinctive individuals. The 1522 sounds recorded were classified into 11 categories based on frequency and temporal characteristics. The predominant call was a descending sweep of frequencies. Parameters measured for this downsweep exhibited a dichotomy of characteristics which indicates calls with initial frequencies below 40 Hz have less variability than calls with initial frequencies above 40 Hz. In general, solitary animals produced primarily the lower frequency downsweeps. Higher frequency downsweeps were recorded from pairs or trios of fin whales. Solitary individuals did not exhibit unique variations in downsweep parameters. No clusters of values which might indicate uniquely individual ranges were consistently present in multiple animal recordings. The data suggest that the variability of fin whale vocalizations is primarily contextual rather than individual.

DEDICATION

to William E. Schevill,
the father of cetacean bioacoustics

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INTRODUCTION

Aristotle authored the first published description of calls produced by dolphins in his Historia Animalium (Schevill et al., 1962). Little new information was added to the literature for centuries. During the search for the Northwest passage, Captain W. Parry (1821) reported hearing the calls of a white whale, the beluga, Delphinapterus leucas. Aldrich (1889) told of sea captains who listened for the songs of whales to help them track their prey, and expressed the opinion that all marine animals with lungs produce sounds. He mentioned both a baleen whale, the humpback, Megaptera novaeangliae, and a toothed whale, the blackfish or pilot whale, Globicephala sp. In addition, early whalers described calls emitted by captured dolphins and stranded whales. Scientists remained unconvinced that whales had a voice, however, as no sound producing mechanism could be found (Slijper, 1976). Documentation awaited the invention of underwater listening devices.

Urick (1967) cited Leonardo da Vinci's description of hearing distant ships through a tube placed below the water surface in 1490 as the first recorded attempt to monitor underwater sound. The development of transducers capable of functioning in an aquatic environment was hastened by the sinking of the Titanic in 1912. British and American scientists patented methods for detection of echoes from large objects, but in 1914 the American, R.A. Fessenden, first demonstrated the ability to detect an iceberg at 3 km using his underwater echo-ranger (Urick, 1967).

The onset of World War I stimulated further research on the possibilities of echo-ranging for the detection of submarines. Between

World Wars the scientific effort was expanded to study environmentally induced variations in the speed of underwater sound and the effect of thermal gradients on the apparent position of targets. World War II stimulated the organization of scientists who studied all phases of underwater sound in an effort to increase the sophistication of military applications. Background noise often affected the ability to detect targets and bioacousticians concentrated on the biological sources of ambient noise in the world's oceans. SOFAR (sound fixing and ranging) stations were placed along the continental slope to continuously monitor underwater sound in 1951 (Thompson, et al., 1979).

In 1948, Schevill and Lawrence recorded the calls of the beluga in the St. Lawrence River and described a myriad of sounds produced by that species, while noting that a minke whale, Balaenoptera acutorostrata, was silent (Schevill and Lawrence, 1949). In 1952, Schevill listened to the calls of the humpback whale, M. novaeangliae in Bermuda (Watkins, personal communication). But it was the occurrence of very low, very intense sounds on the SOFAR station recordings that stimulated funding for a concentrated study of baleen whale calls. In 1964, Schevill et al., identified the fin whale, Balaenoptera physalus, as the source of a 20 Hz call described from the SOFAR station recordings (Walker, 1963, 1964; Patterson and Hamilton, 1964; Weston and Black, 1965; Kipplewhite et al., 1967; Northrup et al., 1971). Interestingly, the source for one of the other low frequency calls is still uncertain, although it is believed to be a blue whale, Balaenoptera musculus. The development of more sophisticated broad-band hydrophones and tape recorders has permitted a great expansion of the study of cetacean sound production.

The Order Cetacea (Phylum Chordata, Subphylum Vertebrata) is divided into three suborders. The Archaeoceti, the primitive whales, were an unsuccessful offshoot from an ancestral marine mammal which probably gave rise to the two living groups: the odontocetes and mysticetes. The suborder Odontoceti includes the following families of toothed whales: Platanistidae (river dolphins), Delphinidae (dolphins), Phocoenidae (porpoises), Ziphiidae (beaked whales), Physeteridae (sperm whales) and Monodontidae (the beluga and narwhal). The baleen whales, suborder Mysticeti, include three families of large cetaceans which lack teeth: Balaenidae (right whales and bowhead), Eschrichtidae (Pacific gray whale) and Balaenopteridae (rorquals). Although the ancestral cetacean is unknown, the presence of toothbuds in embryonic mysticetes indicates a toothed ancestor. The point of divergence between the odontocetes and mysticetes is unknown (Gaskin, 1976).

Annual migrations are undertaken by baleen whales from the lower latitude breeding grounds to the higher latitude feeding grounds, for both hemispheres, in the spring and early summer. They return to the breeding grounds in the fall and early winter. The distance of the migration varies, and some populations may remain in fairly restricted areas year round (Gaskin, 1976). It is unlikely northern and southern populations interact due to the opposing migration patterns.

The baleen whales exhibit a variety of feeding strategies, from the specialization of the blue whale, stenophagous on the larger species of krill (Crustacea: Euphausiidae), to the generalists, such as the fin whale and the minke whale, which take krill or schooling fish, depending on their geographic location and local abundance.

In the feeding grounds, the mysticetes are solitary or in small groups. Occasionally large groups of whales are seen feeding on fish

(Tomilin, 1967). The quantity of food required and the feeding strategy favor spacing and little cooperative feeding has been observed. Large groups of animals are frequently encountered in the breeding areas. The search for food or conspecifics would be simplified if particular geographic locations are utilized annually. However, the whale must locate that site, or locate conspecifics over long distances.

The utilization of sound for communication has the advantage of rapid signal transmission which permits exchanges between animals who can continue to move through the environment (Marler and Hamilton, 1967). Therefore it is not unexpected that sound may be used by cetaceans to maintain contact with conspecifics, to navigate, or to locate food items (Norris, 1969; Thompson et al., 1979). Beamish (1970) defined the frequencies used and the power of each as the acoustic window. The acoustic window a species uses is influenced by reflectivity on the lower end and attenuation on the upper end (Beamish, 1970). In addition there may be species-specific constraints which limit the range of vocalizations produced to permit species recognition. Sound production is an important aspect of the behavior of both odontocetes and mysticetes, although the vocalizations vary markedly.

Sound production is better documented for toothed whales than for baleen whales (see reviews by Schevill, 1964; Poulter, 1968; Evans, 1973; Sales and Pye, 1974; Caldwell and Caldwell, 1977). Most of the definitive work on cetacean sound production and function has been conducted with the bottlenose dolphin, Tursiops truncatus, because this species adapts well to confinement and trains easily. Other toothed whales have been studied to various degrees related to their adaptability to aquaria and their occurrence in the wild. Norris (1969) discussed the types of sounds produced by odontocetes and designated

two categories: the broadband click and the narrow band whistle.

Clicks have a wide frequency range (or bandwidth), 6 to 150 kHz, and repetition rates from five per sec to several hundred per sec. It is believed this wide frequency range can provide the dolphin, or whale, with general environmental characteristics from the lower frequency components and more detailed information from the directional higher frequency components. The more rapid attenuation rate of higher frequencies restricts their usefulness to shorter distances. Clicks are the only phonation produced by cetaceans that have been clearly demonstrated to function in echolocation. In fact, some species seem to be restricted to click emissions: the sperm whale, Physeter catadon (Watkins, 1977; Watkins, 1979), the Phocoenidae, and the members of the river dolphin family, Platanistidae (Norris et al., 1972; Pilleri et al., 1976; Caldwell and Caldwell, 1977). Sperm whale clicks are produced in sequences which are individually identifiable and may serve as communication signals as well as echolocation signals (Watkins and Schevill, 1977; Watkins, 1979). Delphinids produce clicks in a variety of behavioral contexts. These calls have been described as barks, squeaks, squawks, grunts, and moans. The characteristic rapid repetition rate presumably cannot be used for echolocation. However, no one has determined the limits of the cetacean acoustic analyzer.

Narrow band squeals or whistles (2-20 kHz) are either pure tones or tones with simple harmonics and durations over one second (Evans and Prescott, 1962). The existence of species specific and individually recognizable whistles has been described for several dolphin species (Evans and Prescott, 1962; Dreher and Evans, 1964; Caldwell and Caldwell, 1971; Caldwell, Caldwell, and Miller, 1973; Hickman and Grigsby, 1978; Gish, 1979). The bottlenose dolphin may also discriminate whistles of

other species (Caldwell, Caldwell, and Hall, 1973; Caldwell, Hall, and Caldwell, 1971). Contrary to the earlier findings by the Cawdwells, Gish (1979) found the production of individualized whistles was context dependent and only a small part of a complex repertoire. She conducted a computer analysis of 19 parameters from whistles produced by physically isolated bottlenose dolphins provided with an acoustic link. Her data show individuals modify a particular whistle type, a "calling whistle", by adding embellishments or deleting components. Gish (1979) also quantified the occurrence of other call types, and found that burst-pulsed sounds, sounds with broadband click components, were produced 70% of the time, in all behavioral contexts.

Dreher and Evans (1962) compared the whistles and context of sound production of several delphinid species. They concluded interspecific communication was possible based on the similarity of some context-related calls, for example, alarm calls. However, Taruski (1979) studied the whistle types produced by free-ranging North Atlantic pilot whales, Gl McBicephala malaena, and found a continuum of frequency versus time contours. Many of the contours had been described by Dreher and Evans, but many other contours were also present. In addition, Taruski (1979) concluded signature whistles and dialects exist for this species.

The baleen whales are generally too large to be maintained in aquaria for extended experimentation and study. To date 10 of the 12 species of baleen whales have been recorded in the field. Most of the data recorded is the result of brief encounters with the animals under less than ideal conditions at sea. Often the source of the calls recorded is debatable, since the animals are visible only during their relatively short surface time when breathing between dives. There

is always the possibility that an unseen animal is the actual source (Thompson, Winn, and Perkins, 1979). In addition, sound production is known to vary seasonally in some species (Schevill, 1964; Thompson et al., 1977; Watkins, personal communication; Clark, personal communication). For this reason, it is difficult to characterize a species' repertoire. Repeated observation and recording in different geographical locations during all seasons is necessary.

Thompson et al. (1979) reviewed the literature on baleen whale sound production and divided the sounds described into four groups, which may be compared to those described for odontocetes. Low frequency moans constitute one group, with frequencies between 12 and 500 Hz, and durations ranging from 0.4 to 36 sec. The 20 Hz call of the fin whale is placed in this category as an example of a pure tone moan. Moans may have harmonic structure.

The second group is comprised of thumps and knocks of shorter duration, from 50 to 500 msec with frequencies between 40 and 200 Hz. Chirps, cries and whistles are the third group. They are higher frequency calls, above 1000 Hz. Chirps are defined as 50 to 100 msec discrete tones that are pulsed and change frequency rapidly. Cries and whistles are pure tones with or without harmonics. No duration range is given.

The highest frequencies and the shortest durations are characteristic of the last group, the clicks. The frequency range is from 2 to 30 kHz. The latter was reported in a controversial recording in the presence of a blue whale (Beamish and Mitchell, 1971). Although the upper frequency range is debatable, the occurrence of clicks has been reported for most species of baleen whales. The rapid attenuation of high frequency sound and the generally low intensity of these calls

may account for their apparent rarity. Two experimental field attempts to stimulate the use of echolocation pulses by baleen whales did not provoke their utilization (Eberhardt and Evans, 1962; Beamish, 1978). Continuous recording of sound and concurrent behavior is needed to clarify the function of sound for the mysticetes.

Thompson et al. (1979) discussed the various roles sound may play for baleen whales. Individual variation has been suggested in the songs of the humpback whale (Hafner et al., 1979) as well as annual and geographic variation (Winn and Winn, 1978; Payne and Payne, 1980). The thump trains reported from the minke whale by Winn and Perkins (1976) may vary individually as may the 20 Hz calls of the fin whale (Thompson et al., 1979). Quantification of the variations recorded from known individuals is necessary.

The opportunities for prolonged investigation of a population of baleen whales are rare. However, three species have been studied extensively in their breeding and calving areas. The gray whale (Eschrichtius robustus) has been studied off California and Baja California, Mexico (Cummings, Thompson, and Cook, 1968; Norris et al., 1977), the southern right whale (Eubalaena australis) has been studied off Argentina (Payne and Payne, 1971; Cummings, Fish, and Thompson, 1972; Clark and Clark, unpublished data), and the humpback whale has been studied off Bermuda (Payne and McVay, 1971; Winn, Perkins, and Poulter, 1971; K. Payne, 1979), the West Indies (Winn and Winn, 1978), Hawaii (Darling, Gibson, and Silber, 1979; Forestell and Herman, 1979; Glockner and Venus, 1979; Herman, et al., 1979; R. Payne, 1979) and Alaska (Jurasz and Jurasz, 1979).

Although the fin whale was one of the earliest mysticetes recorded, little new information has been added to the literature. No mating

or calving grounds have been discovered for fin whales in the Atlantic, although Hobbs (personal communication) believes a site may exist in the Pacific. Work by several investigators suggests different call types exist. The most frequently recorded is the 20 Hz call, described by Schevill (1962) as a frequency sweep from 23 to 18 Hz. Later Schevill and Watkins (1972) recorded a higher frequency descending call, or down-sweep, from approximately 75 to 40 Hz. In addition, Watkins (personal communication) has heard a long rumbling call of low frequency.

Thompson and Cummings (1969) described three types of signals recorded off Puerto Refugio: a 68 Hz call, 0.6 sec duration; a 34 Hz call, 1.8 sec duration, and a 60 Hz call, 0.6 sec duration with some intra-signal frequency shifts. They did not record any 20 Hz calls. A controversial recording of chirps and whistles, 1.5 to 5 kHz, was reported by Perkins (1966), and attributed to a fin whale. No other investigator had reported such calls for this species. However, Thompson et al. (1979) recorded a series of high frequency pulses, 16 to 28 kHz, with 3-3.4 msec durations as two fin whales approached their ship. Only one investigation has recorded both low frequency and higher frequency calls. Patterson and Hamilton (1964) found a 140 Hz tone preceded a loud 20 Hz call that was part of a series of double calls.

In 1973 Dr. E. Mitchell of the Fisheries Research Board of Canada initiated a whale watching project from a site on the St. Lawrence River's north shore (Mitchell, 1975). That project recorded the occurrence of cetaceans in the area on a year round basis. Several Balaenoptera spp. enter the estuary annually. The predictable occurrence of these species and their behavior suggest the St. Lawrence River is a feeding area of some importance. As one of the summer observers during the three year study, I became interested in expanding the research to determine the role sound may play in the whales' behavior.

The fin whale is a pelagic species (Tomilin, 1967) and, therefore, difficult to study. However, this species frequently passes within several hundred meters of shore in the Laurentien Channel of the St. Lawrence River, providing a unique opportunity for shore-based observation and acoustic monitoring from a fixed hydrophone. The occurrence of solitary adults, pairs, and pods of fin whales offers a variety of contexts for sound production. The presence of ship and boat traffic constitutes another variable which may negatively affect communication for the whales and influence the types of sounds the whales produce.

This study was undertaken to quantitatively describe the types of sounds produced by fin whales in the St. Lawrence River and to compare them with those reported by other investigators. Emphasis was placed on identifying the context of sound production for correlation with vocalization characteristics. In addition, individual identification by dorsal fin shape was attempted to facilitate detailed analysis of the calls for individual variation.

MATERIALS AND METHODS

Data Collection

The field work was conducted from a site on the north shore of the St. Lawrence River from 14 June to 28 September 1980 (Fig. 1). During the first two weeks of the study specific sites were chosen for the hydrophone and preamp, a shoreline tent, and an observation hut. The hydrophone-preamp (KSP HS 107-220) was anchored by divers 90 m off shore, in water 6-10 m deep, depending on tidal cycle. This assembly was mounted on a wooden dowel and floated 1.2 m from the bottom. A truck gear and several rocks provided anchorage.

Examination of the bottom indicated little turbulence in the area chosen, as evidenced by the presence of castes from polychaete burrows, and the presence of several species of sea anemones, sea cucumbers, and tunicates attached to all sides of the rocks. For this reason, the cable from the hydrophone anchor to the intertidal zone was placed directly on patches of sand or between large adjacent rocks. In addition, it was looped to nylon line at one meter intervals to prevent horizontal stress (Fig. 2). In the intertidal zone the cable was covered with garden hose and placed between smooth rocks to protect it from wave action. The cable lay along the shoreline another 23 m to the site of the shoreline tent, approximately 20 m above the high water mark. The hydrophone system was connected to the amplifier (KSP ACS 601, modified) housed in the tent with the tape recorder (Nagra IV SJ). All equipment was battery powered.

Output from the hydrophone and amplifier was fed into channel 1 and the FM comment channel of the tape recorder. This dual input provided an effective frequency response of 10-20,000 Hz for the

entire system as limited by the preamp. A frequency response test of the Nagra, channel 1, showed a flat response from 30 Hz to 40 kHz. The response was -2 dB at 20 Hz, and -5 dB at 10 Hz (Fig. 3). The FM channel required a signal 20 dB louder than channel 1. This was accomplished by increasing the amplification of the signal from the hydrophone-preamp to accomodate the FM channel, while attenuating the signal to channel 1 with the attenuator on the Nagra. Channel 2 was only used for commentary. Recordings were made at 19 cm/s ($7\frac{1}{2}$ ips). Usually 549 m (1800 ft) reels of tape were used as available (Scotch 212 and Ampex 624, both 1 mil thick with equivalent biases).

An observation hut was built on the hillside 200 m above sea level and 0.3 km from the shoreline tent. The hut was behind the position of the tent and hydrophone to permit coordination of observations from both sites. Two side windows and a large front window on the hut gave the observers a 160 degree view of the river. The relative narrowness of the river allowed us to scan its 15 km width on clear days. Watches were conducted without optical aids. Binoculars (7 X 35) and a spotting scope (25X) were employed for behavioral observations and periodic scans of the area.

Daily observation varied from 14 to 12 hrs as the day length decreased during the study. Individual observers in the hut had 2 hr shifts to minimize fatigue, but the resting observer was available as an assistant for multiple sightings. I was positioned in the tent or on the shoreline throughout the observation day. The upstream view of the river was better from the tent site, but the downstream view was better from the hut. Together we could see whales approaching from 4-5 km depending on weather conditions and the visibility of the blow.

During August and September, 20 min scans were conducted every 2 hr, weather permitting, using binoculars and a spotting scope. If a whale was under observation, the scan was conducted following the disappearance of that whale. When visibility was very good, over 8 km, and whales were abundant in the area, the scans often took longer than the designated 20 min. Whenever possible, the second observer continued to watch for close whales which could be missed during the scan. The whales sighted during scans gave a general idea of the number and species of whales in the area which may have contributed to the background noise during tape sessions.

Acoustic "monitors" were conducted every hour for 10-15 min, coinciding with the visual scan whenever possible. A monitor consisted of continuous listening to underwater sound using headphones connected to the tape recorder. The sound level meter of the tape recorder was observed simultaneously. Meter deflections which did not coincide with audible sound were interpreted as the occurrence of sounds below my hearing range. Occasionally an acoustic monitor was recorded for comparison with tapes recorded in the presence of baleen whales. Descriptions of audible sounds, meter deflections, or the lack of sounds was always entered in the acoustic notebook. No filters were used during the study despite ship noise and 60 Hz noise because sounds produced by the fin whale occur in this frequency range.

Whales within approximately 1.6 km of shore were visually followed, recorded if acoustic conditions permitted, and photographed whenever possible. When a whale was sighted, the tent and hut coordinated activity via two way radio. A sighting was defined as any whale, or whales traveling together, of a particular species, beginning

at a given time on a given date. Each whale sighting was designated by these parameters: for example, fins x2, 12:20 18 August 1979. Behavioral data were recorded on standardized data sheets listing blow times, direction of travel, nearest landmark, distance off shore, and any specific behavioral comments. In addition, the tide times, visibility, sea state (Beaufort scale), water color, and sky conditions were recorded for each sighting. A cassette tape recorder was used during multiple sightings. Behavioral comments were also recorded on channel 2 of the Nagra when whales were visible from the tent during taping sessions.

We attempted to photograph the dorsal fin of every whale within 0.8 km of shore when the whale crossed in front of the photographer on shore. A 400 mm lens on a 35 mm camera was operated from the tent site, and a 500 mm lens was used by a mobile photographer positioned either upstream or downstream of the tent site with another 35 mm camera. The dorsal fin was photographed when the whale's back rose above the water, parallel to shore, following a blow during a blow series. The last blow of the series (followed by the terminal dive) was not photographed as the back is usually more arched and the dorsal fin is somewhat distorted. Bulk Plus X (ASA 125) and Tri X (ASA 400) were used for the dorsal fin photographs. Kodachrome (ASA 64) and Ektachrome (ASA 200) were used for slides.

Two all-night monitors were conducted on 11 July and 8 August. The 8 August monitor coincided with a 24 hr watch from the hut. Night watches had been conducted as part of a feasibility study in July 1978, using US Army night vision equipment. No night vision equipment was available for the study this year, but a full moon on a cloudless night provided some visibility. During the 1978 study we

confirmed that differences in nocturnal respiratory patterns can be used to distinguish minke whales from the larger species, but cannot distinguish fin whales from blue whales. However, minke whale blows are far less explosive and cannot be heard for nearly as great a distance even during the calm of the evening. Weather conditions did not permit a 24 hr watch in September.

Each evening the daily notes were transcribed into the main notebook. Acoustic data were logged by reel number, date, and species. Photo data were logged by roll, number, date, and species. Appropriate cross references were also made in each file. Each whale sighting was given a behavioral code: 'straight' for a whale seen for two or more series of blows headed in only one direction for the entire observation period; 'straight x2' for a whale who went one direction for several series, and then reversed direction, traveling in that direction until lost from view; 'circling' for the formation of a circular surface disturbance by a minke whale, apparently during feeding; 'active' for whales with particularly energetic blows, brief surface times, numerous direction changes, surface disturbances between series, or a flipper or fluke breaking the surface; 'missing' for whales which were not followed, such as whales seen during a scan or whales that were seen for one or two blows only; 'no pattern' for whales whose behavior did not fit any of the above categories. The behavioral code was included on a daily summary sheet which outlined the sightings for the day. In addition, a minimum and a maximum number of each species was determined using all the sightings for that day. The minimum was determined by the number of distinguishable individuals or the largest number of animals seen simultaneously. The maximum included all whales

that could be different individuals. For example, a pair of fin whales was sighted at 12:00 h. Neither animal had any apparent distinctive characteristics. A solitary fin whale with no apparent distinctive characteristics was sighted at 14:30 h. The min-max for the day would have been 2-3 fin whales, since the third whale may or may not have been one of the pair seen previously.

Lastly, a ship file was maintained. We recorded the time any ship or boat passed within approximately 3 km of the tent. The direction of travel was also included, as ships passing upstream had a greater effect on background noise level. Some of the ships and boats, including a hydrofoil, were recorded for noise level documentation.

Sampling tows were attempted using a 3.6 m fishing boat with a 1.2 hp motor and a 0.5 m diameter ring bridle net. A pint jar was attached to the cuff. Water samples for salinity measurements were taken from the surface monthly, and from 6 m depths during two dives. Water temperature was measured during the dives using a Heathkit temperature probe (ML-104).

An assistant and I made a total of nine dives. The first three were made at different sites to determine the best position for the hydrophone-preamp system, following examination of the depth contours near shore using a Heathkit fish spotter (ML-2901). Two dives were required for complete installation. Maintenance dives were conducted on 6 July, and 26 August to remove algae from the system. The hydrophone-preamp and cable were removed on 29 September. We left the site the following day.

Data Analysis

Each of the tapes was reviewed three times. The comment track

(channel 2) was transcribed first. Secondly, channel 1 was reviewed at the same speed at which it was recorded. Audible sounds were subjectively described and compared to the background noise. Finally, the tape was monitored during rewind. Rewind speed is approximately 13 times faster than the recorded speed. Therefore, sounds below human hearing are 13 times higher in frequency and are audible. The duration is only $1/13$ as long, however, and does not allow one to characterize the sound well.

Using the information gained from reviewing each tape, I evaluated the quality of the recording and assigned a 'Q' value to each recording session. A Q of 1 was assigned to a tape with few audible sounds (on forward and rewind) or a tape with very high noise levels. A Q of 2 was assigned to a tape with intermittent sounds, but was also assigned to a tape for which there were few behavioral observations. The highest value, a Q of 3, was assigned to a high priority tape which was likely to yield the best combination of acoustic and behavioral data. My initial analysis was restricted to the better tapes in order to familiarize myself with the nature of the data prior to attempting to analyze the lower quality tapes.

Two methods of sound analysis were employed to maximize the measurement accuracy for the following parameters: initial, final, higher, and lowest frequencies (FI, FF, FH, FL); call duration (TD); intensity (I); and intercall interval (ICI). A real time spectrum analyzer (RTA Princeton Applied Research model 4512) provided continuous fast Fourier analysis of the taped sounds. The time window (the time required to complete one input record) on the RTA was 2.5 s on the 1-200 Hz scale used for all of the call measurements. I used fixed gain viewing, which provides intensity lines 60 dB below input full scale. The Nagra output was attenuated

20 dB at all times as increasing or decreasing the attenuation could change the apparent intensity of the call, as well as change the apparent duration.

The output from the RTA may be reproduced on 9 cm wide paper from an EPC graphic recorder (Model 1400) or displayed directly on a Unigon scan converter screen (Model SC-1). The RTA hard copy resolution was not superior to sonagrams or the screen, and equipment malfunctions limited its use for data analysis. Therefore, the Unigon screen was used for all frequency, intensity and duration measurements.

Frequency was measured from the center of the 1.6 Hz bandwidth displayed on the Unigon screen. The 1-200 Hz range produces a 1 Hz/mm scale. Since the accuracy of the bandwidth was ± 0.8 Hz, I measured frequency to the nearest millimeter, or 1 Hz.

Intensity is displayed by graded levels of brightness on the Unigon screen, in 6 dB increments. The maximum number of brightness levels is 10 (60 dB input full scale/6 dB increments). The most intense portion of the call is displayed most brightly. A cursor was set on the highest intensity frequency components of a call, and the value displayed by a digital readout was recorded along with the frequency at that intensity. The cursor only functions when the tape is running. Therefore, intensity measurements were not made for all the frequency components.

The call duration measurement was taken from the initiation of the call (6 dB above ambient noise) to the final visible component of the call (Fig. 4). This measurement may have included reverberation or distortion due to the signal pathway, but represents the duration received by another whale in the area. These measurements were made from the screen rather than from a sonagram for several reasons. The

apparent duration of a sonagram representation is greatly affected by record, reproduce, and mark levels which are operator controlled in response to the sound level produced over the period recorded on the sonagraph. The reproduce level is determined by the average intensity of the entire recorded portion. Therefore, a very loud call may dictate a reduced reproduce level so as not to burn the paper. Any less intense calls are thereby reduced and may appear to be of shorter duration than they actually are. This variation limits the accuracy of comparisons of consecutive sonagrams for duration measurements. The 6 dB intensity increments on the RTA screen provided sharp onset and termination of a call and allowed more consistent measurements. The duration measurement is, therefore, less subjective than one from a sonagram. However, since the fin whale calls were generally louder at initiation than termination, the sonagrams could be used for intercall interval using the interval from the beginning of one call to the beginning of the next (Fig. 4).

I used the 5-500 Hz range on the sonagraph (Kay 6029) to maximize the number of calls per sonagram. With a 38 cm/s (15 ips) playback speed, the effective analyzing frequency range was 2.5-250 Hz. Doubling the recorded speed for analysis sharpened the onset of the call and increased the precision of my measurements. Both wide band (19 Hz bandwidth) and narrow band (2.8 Hz bandwidth) overlapping sonagrams were produced. Wide band was used for most intercall interval measurements. Narrow band sonagrams were superior when noise levels were high below 60 Hz, causing interference with the calls if wide band was used. The scale magnifier (Model 7076C) was used to compare call structure for some sessions involving more than one whale. Continuous monitoring of the tape was necessary to be certain no calls above 250 Hz

were missed during both the screen measurements and the production of the sonagrams.

The underlying purpose for the detailed examination of the sounds and their occurrence was to describe the variability observed and attempt to correlate that variability with an individual or context. During the analysis different structural variations were noted. In order to understand how individuals may vary the calls they produce, a preliminary quantification of the overall variability was necessary. This was accomplished by the calculation of descriptive statistics for the call structures in the total file. The distributions of variables measured (FI, FH, FL, FF, FD, TD, ICI) were plotted on frequency histograms to determine the degree of overlap between structures.

Concomitant variation, the extent to which the variation of one parameter is related to another, had to be explored for each structure as well before individual variation could be investigated. Scattergrams were produced to determine whether pairs of variables covaried. This method of correlation analysis does not distinguish between independent and dependent variables nor does it assume a linear relationship (Sokol and Rohlf, 1969). It is appropriate for variables whose source of variability may be the same. If the relationship is linear, the strength is evaluated by Pearson's product moment correlation coefficient, r , which varies from -1 for strong inverse relationships to $+1$ for strong positive relationships. Significance tests are inappropriate unless both variables are normally distributed (Sokol and Rohlf, 1969), however, r^2 , the coefficient of determination, expresses the proportion of variation of one variable which is determined by the variability of the other. For r^2 to be greater than 50% (or .5) r must be greater than 0.7.

Stepwise discriminant analysis was used to determine if a set of discriminating variables could be used to classify call types correctly. The method is robust and strong adherence to the assumptions of normality and homoscedasity is not considered necessary by some statisticians (Klecka, 1970). However, greater differences in variance will decrease the statistical significance of the functions. Neff and Marcus (1980) suggest differences in variance may be important biologically, but caution the results of the discriminant analysis will be skewed by the largest variance.

The recording sessions were examined for the frequency of occurrence of each structure. The predominant structure was chosen to analyze inter- and intra-session variation in that structure's characteristics. Histogram plots were constructed to determine the degree of inter-session overlap and facilitate identification of the variables that may contribute to individual identification. Scattergram plots were produced to compare concomitant variation for different sessions and sightings. The coefficient of variation was calculated ($s.d./mean \times 100$) for comparison of similarly distributed parameters between sessions and sightings. The sessions were also subjected to stepwise discriminant analysis in an attempt to determine which combination of parameters may be responsible for the variability observed. Large sessions were reduced to a number of subsessions to facilitate comparison (Appendix 1). Two discriminant runs were conducted. The first included only sessions with similar variances and covariances (Appendix 1). The second included all sessions and subsessions with values for all the parameters considered as a test for overall similarity. An F matrix (for comparison of variance) and a computer plot of group centroids produced from the

discriminant function axes permitted a visual comparison of session similarities and differences. A summary of the computer analyses is presented in Table 1.

Lastly, the results from these analyses were compared for known animal recordings based on dorsal fin variations. This technique had not been used previously for fin whales. The comparison of photographs of individual whales for identification of individuals by scars and irregularities in the dorsal fin was begun by Bigg et al. (unpublished data) during a study of killer whales, Orcinus orca. This technique has been used primarily on odontocete cetaceans (Irvine, et al., 1977 and Shane, 1977; Wursig and Wursig, 1977, Saayman and Taylor, 1979), however, dorsal fins have also been photographed to facilitate reidentification of humpback whales using fluke coloration patterns, flipper coloration, and facial grooves as well (Levenson, 1969; Darling et al., 1979; Glockner and Venus, 1979; Katona et al., 1979; Lawton et al., 1979). For this study we used enlargements of dorsal fin photographs taken from the same and from different sightings. Photographs of the same animal or animals taken during a continuous sighting acted as controls. An artist and I separately sorted the photographs into groups of the same individual. Those which we agreed upon were classified as the same whale; those which we did not agree upon were classified as 'possibly' a particular whale. The characteristics used were angle of the leading edge, shape of the tip, angle of the trailing edge, apparent height above the back, and any irregularities such as notches or tears (Fig. 5).

RESULTS

Observations

Daily observations were conducted from 28 June to 27 September 1979, a total of 14 weeks. Observation began at sunrise and ended at 19:00 h for most of the season. We had 65 full days of observation, 24 days of partial observation (due to fog or heavy rain) and 7 days of complete fog, with no observation. The number of fin whale sightings per observation day is graphed in Fig. 6. Whales sighted during scans could not be distinguished between scans and were always counted as new whales. This practice indicates utilization of the area rather than the absolute number of whales in the area on that day. Therefore, the absolute number of whales lies somewhere between the minimum and maximum value graphed for each day.

Table 2 contains the number of sightings and the number of sightings followed for the fin whale, B. physalus, and two other species in the study area, the minke, B. acutorostrata, and the blue, B. musculus. Each sighting was given a value of one and whales traveling together were counted as one unit. Fin whales frequently occurred as pairs or groups of three to six animals. The occurrence of these categories during the study is presented in Fig. 7. Most of the groups of three animals were seen during scans, and all of the larger groups were only seen several kilometers away from shore during scans.

Most of the whales moved through the study area on straight course, or showed no pattern (Table 2). Tabulation of direction of travel indicated no preference for moving upstream or downstream through our area. However, direction of travel exhibited a diurnal pattern. Fin whales were headed upstream more frequently than downstream before

12:00 h (75%). The downstream course was slightly favored in the afternoon (57%). Whales sighted during scans were not followed to determine their course and were not included in this comparison. The addition of that data may alter the apparent trend to travel upstream in the morning.

All followed whales sightings were plotted on a histogram according to the time of first sighting to determine if activity patterns existed which may have affected the acoustic data gathered during particular hours of the day. Four different graphs were needed to take day length into account, and all values were converted into percentages of the total sightings during the period to standardize sample sizes (Fig. 8). No one pattern was consistent throughout the study. The night monitors indicated that if the whales passed by at night, they did so far off shore, as we did not hear blows during either of the two night sessions. Night acoustic monitors did not reveal any high intensity sounds although distant low frequency calls were recorded once.

All followed whales and all whale sightings during scans were placed on a tidal cycle histogram based on one hour increments on either side of the high tide. Although sightings of distant whales were time dependent (due to the scan schedule) the monthly tidal cycle should have negated that effect and all were included in the tidal effect study. The whales did not travel with or against the tide, even if one considers only whales traveling a straight course upstream or downstream (Fig. 9). Therefore, the occurrence of fin whales in our area is not dependent upon tidal cycle.

Our attempts to measure environmental parameters were limited due to their secondary nature during this study, and the negative effect that time spent sampling may have had on behavioral observation.

The data presented here is from irregularly spaced samples that were a function of available personnel and the diving schedule.

The water temperature at 10 m varied from a low of 1.1°C in June to a high of 3.3°C on 2 September. As would be expected, the surface temperatures were more variable, but ranged from 2.2°C in June to 8.8°C on 18 July. On 2 September, the surface temperature was already reflecting the cooler weather at 4.4°C . By 29 September, the surface temperature was 3.3°C and the 10 m temperature was again 1.1°C .

The salinity measurements were made from water samples taken at the site and during dives. The values obtained were highly irregular, but indicated the salinity in the area was quite high, between 29 and $33^{\circ}/\text{oo}$.

The tows with the ring bridle net were largely unsuccessful. Few cetacean prey items were captured. On 18 July the tow yielded several fish larvae, copepods and brown algae. The 15 August tow contained only copepods. During the 17 June dive, a school of approximately 1,000 small silver-sided fish were observed at a distance. On 2 September small silver-sided fish were jumping at the water surface. Attempts to capture a fish from the boat were unsuccessful. During our last dive on 29 September, I saw approximately 15 small fish which appeared to be juvenile capelin, Mallotus villosus. Feeding behavior was rarely observed for all baleen whales. Local fishermen were catching moderate numbers of capelin, cod and flounder. Fewer mackerel slicks were seen this year than in 1973-1975. Although no quantification of prey biomass was possible, it is likely the area did not have an abundance of suitable prey items for the baleen whales.

Ship Traffic

A total of 1161 ships and boats passed through the study area between

28 June and 27 September. The ships were plotted on a histogram to determine if their presence was concentrated in particular parts of the day which could bias the recording effort to only the times when the ships were not in the area. The ship traffic was slightly greater before noon (65%) but was fairly evenly distributed throughout the day. Therefore the effect of ship noise can be considered random. Of the animals sighted near shore and followed, recording was possible in only 27% of the minke whale sightings, 31% of the fin whale sightings, and for one of the two blue whale sightings (Table 3). The approach of a ship during a sighting increased the noise level approximately 10-15 dB as indicated by the required increase in attenuation to prevent overloading the tape recorder. On one occasion the noise level was increased by over 24 dB by a Norwegian ship (Brage Pacific, 18 August, 06:30 h). Although I usually ceased recording when ships approached within 1 km of the hydrophone, one tape included a period during which a passing ship stopped its motors. When the ship started again, the whale sounds were partially obscured due to the overlap in frequency and the higher sound pressure level of the ship (Fig. 10). Two long intercall intervals (36 and 45 s) occurred just as the ship noise increase required a 4 dB increase in my Nagra attenuation to permit continued recording. The intercall interval averaged 5.5 s prior to this pause and 8.5 s following the pause. No other variations were obvious after the ship noise increased.

Individual Identification

Over 1,000 photographs of whales were taken in an attempt to identify individuals by dorsal fin shape. Thirty-four rolls of Plus X and 16 rolls of Tri X were used. The parameters outlined in the methods section were used successfully to sort the same individual's photographs

from the same sighting. The photographs could then be distinguished for animals of different sightings with confidence. Enlargements of the dorsal fin was necessary as some variation due to water or lighting effects were only apparent with comparison between similar enlargements. One fin whale seen in 1973, 1974, and 1975 during Mitchell's study was resighted during our study. A photograph from Mitchell's files was compared to ours and the unusual dorsal fin had not noticeably changed. Sightings of distinguishable animals which had produced sounds comprised the subsample analyzed for individual variation (Fig. 11).

Sounds Recorded

A total of seven 365 m reels of tape and forty-six 549 m reels of tape were used to record the three species of baleen whales, the minke, fin and the blue; beluga whales; and a variety of ships. Recordings were made of background noise during different sea states to document wave noise. One sighting of a bottlenose whale, Hyperoodon ampullatus, was recorded, but no sounds were on the tape which could not be attributed to belugas or baleen whales. Samples of minke whale and blue whale calls were compared to the fin whale sounds to facilitate identification of source during multispecies recording sessions. The sounds were separable primarily on duration and frequency parameters.

Call intensity was not a reliable predictor of source during this study. Intensity varied from 66 to 108 dB re 20 μ Pa for all the calls examined during the study. One particular call was always less intense than others in the same session and it is responsible for the lower end of the range. There was no consistent variation in intensity as a whale passed through the study area or varied its orientation with respect to the hydrophone (Fig. 12).

Comparisons of sounds heard in the presence of fin whales with those in the absence of fin whales was reassuring evidence that the whales which had been observed during a recording session were the source. The large size of the observation area eliminated the possibility that a fin whale could pass within 1.6 km of shore without surfacing for a respiratory series which would be visible and frequently audible as well.

Fewer fin whales were observed in our area during the first month than during any other time of the study and no fin whale sounds were recorded before 14 July despite numerous attempts in the presence of close individuals and pairs (Appendix 2). The next recording with fin whale sounds was 31 July. In August and September only two sessions (13 and 15 min) did not have any sounds. The lack of sounds may be due to the briefness of the recording session, however, sounds were present on briefer recording sessions (Appendix 2). Recording opportunities were limited by ship noise. Therefore the sample of recordings was not random nor was it an exhaustive attempt to record the occurrence of fin whale calls. Recordings were only made when a fin whale was less than 2 km from shore, within our visual range, when background noise levels permitted me to monitor sound level fluctuations during a sighting. My results indicate there was less sound production in July when there were fewer whales in our area, but systematic documentation is necessary before any conclusions may be reached. The number of calls produced tended to increase with the number of animals in the sighting, indicating more than one animal was calling. Silent groups also occurred (Appendix 2).

I examined 1645 sounds recorded in the presence of the fin whale. Only 1522 could be clearly distinguished from the noise for further analysis. These sounds were placed in one of 11 categories based on

the structure of the call, the frequency range, and the duration (Figs. 13-16). Ten of these structures were distinct sounds while the final was a continuous long call or rumble. Frequency and duration parameters are plotted in Figs. 17-18 for comparison. Overlap between most of the structures is apparent. The relative occurrence of the ten call structures for the total file is shown in Fig. 19. Because of the difficulty in determining when one long call ended and the next began, the rumble was not quantified by the number of individual occurrences as were the other structures, but was only recorded by its presence or absence during a particular session. Therefore it is not included in Fig. 19, but appears in Appendix 2.

Eighty-two percent of the calls were structure 1, a downsweep (Fig. 13). A downsweep is a relatively continuous drop in frequency from initiation to termination of the call. The frequency sweep is most rapid at the beginning of the call. The initial frequency (FI) is the highest frequency (FH), and the final frequency (FF) is the lowest frequency (FL). Although FI ranged from 14 to 118 Hz, 60% of the calls had an FI between 21 and 31 Hz. The FF was between 16 and 21 Hz for 73% of the calls. The FF had a definite mode at 18 Hz. Initially no distinction was made for frequency, however, examination of all downsweep parameters indicated there are two downsweep types. A plot of FI and FF (SPSS/scattergram) shows a strong relationship (Fig. 20), but a cluster of points in the lower frequency range (10-40 Hz) was not adequately represented. The same is true for the plot of the frequency difference (FD) and FI. In this instance, the plot is increasing rapidly between 15 and 45 Hz, then the increase levels off asymptotically (Fig. 21). Expansion of the scales for both plots revealed two different trends, indicating two types of downsweeps exist. For frequencies

above 44 Hz, the FF versus FI graph has a steeper slope and a higher correlation coefficient than for $FI \leq 44$ Hz (Figs. 22,23). The graph of FD versus FI has a correlation coefficient of .7984 for $FI \leq 44$ Hz (Fig. 24), and no correlation for $FI > 44$ Hz. Examination of both sets of graphs indicated the change in parameter association may actually occur with initial frequencies around 40 Hz. Comparison of FF versus FD indicated the final frequency clump below 30 Hz is related to the same phenomenon (Fig. 25). A corresponding cluster of FD values occurs below 20 Hz on both graphs.

FD had a range of 1 to 42 Hz for the downsweep. However, 50% of the calls had a frequency difference between 6 and 10 Hz. The durations measured for the downsweep were between 0.2 and 1.8 s. Sixty percent were between 0.5 and 0.9 s.

The constant frequencies call is the second call structure observed during the analysis (Fig. 13). It lacks the frequency sweep of the downsweep. Nearly all the frequencies produced during the call are present throughout. The FH values appear to be bimodal and two groups of constant frequencies calls may exist. A peak occurs between 18 and 21 Hz (39%) and another occurs at 60 Hz (8%). The latter may be a measurement error as 60 Hz noise was always present and hampered measurement between 58 and 62 Hz. However, the FL measurements are also bimodal. One peak occurs at 16-18 Hz (40%) and another occurs between 36 and 40 Hz (15%). The most definitive parameter is the frequency difference. Sixty-nine percent of the constant frequencies calls had a bandwidth of 1 to 6 Hz. There is a second peak between 10 and 11 Hz. The entire range is also smaller than that of the downsweep, only 1-28 Hz. The constant frequencies call FD appears to be more consistent

than that of the downsweep, as indicated by the lack of scatter in the plot of FL versus FH (Fig. 26). The duration of the constant frequencies call is shorter than that of the downsweep: 70% of the calls were between 0.3 and 0.6 s. The intensity (IN) of the constant frequencies call tended to be less than the other calls in the same sighting. IN values ranged from 66 to 96 dB re 20 uPa with a mean of 88 dB.

The third structure is a combination of a constant frequencies call and the downsweep. This call was not recorded frequently and may or may not be a separate call type. The combination call has the appearance of a wide-band call with the lower frequencies exhibiting the downward sweep (Fig. 13). The frequency range is more limited than for either downsweep or the constant frequencies call (Fig. 17). The distribution is strongly bimodal. However, only fourteen of these calls were examined and this limited sample may not be representative of the true distribution. The FD distribution is greater than for either of the two previous structures. The duration of the combination call varied from 0.4 to 1.7 s. One-fourth of these calls were 0.6 s and half were between 0.4 and 0.8 s.

The fourth structure recorded is a tone associated with loud downsweeps. The tone had different forms that were not classified separately. Most frequently it was a constant frequency (33%). The remaining tones showed a frequency rise, drop, or slight internal frequency modulation. Although the tone initially appeared to be nonharmonic, sonagrams revealed a possible fundamental in the 20-25 Hz range which merged with the downsweep following the tone (Fig 14). the FI range for the tone was 129-150 Hz, however, 61% were between 136 and 140 Hz. If the 20-25 Hz component is a fundamental, the audible portion of the call is a 6th or 7th harmonic. No other harmonics were

visible or audible. The duration of the tone was always shorter than that of the downsweep that followed. Seventy-one percent had durations between 0.3 and 0.7 s. The intercall interval for the tone was far more consistent than the interval for any other call. The time from the beginning of the tone to the beginning of the downsweep was 0.5 s or less for 30% of the tones, and 70% had an intercall interval of 0.7 s or less, illustrating the overlap between the termination of the tone and initiation of a downsweep. One tone was recorded with an intercall interval of 43 s. This call is not very intense and may occur more frequently than was perceived during this study. Tones were heard that were too soft to be seen on the RTA screen or a sonagram. The intensity range for the tone was 66-96 dB (mean = 84 dB). Comparison of the calls preceeding and following the tone revealed considerable intensity differences. The call preceeding averaged 94 dB (range: 75-106) and was the loudest of the three calls 44% of the time. The preceeding and following calls were equally loud for 38% of the tones. The following call averaged 93 dB (range: 75-106) but was the loudest of the three only 6% of the time. The tone was never the loudest call, although once the intensity was equal to that of the following call. Overall the tone is 5-19 dB less than the loudest call associated with it.

The fifth call type is a variable frequency call or waver (Fig. 15), FH is greater than or equal to FI and FL is greater than or equal to FF. Only six of these calls were recorded. The frequency ranges are comparable to those of the downsweeps. The durations were fairly long, 0.7 - 1.0 s. No scattergrams were produced for this call due to the small sample size (n=6).

An upsweep was recorded twelve times (Fig. 15). The upsweep is characterized by an increase in frequency over time. The initial

frequency is the lowest frequency of the call and the final frequency is the highest ($FI = FL$) and ($FH = FF$). The frequency range recorded is broad, from 20 to 89 Hz for FI and 24 to 117 Hz for the FF. The FD is fairly small, from 4 to 28 Hz. Most calls exhibited a sweep of 4 to 7 Hz (50%). The upsweep duration range was shorter than that of downsweeps. Most of the upsweeps were 0.4 s (25%) or 0.7 s (33%).

Structure 7 is another infrequently recorded call ($n=19$). However, the structure is very distinctive (Fig. 15). The call apparently rises and falls simultaneously, splitting from the initial frequency. The highest frequency is greater than the initial. Because the lower portion of the split call is sustained beyond the upper portion, the final frequency is the lowest frequency. No other form of the split call was observed. Both the initial frequency and the high frequency values are in the same range as those recorded for the downsweep. The frequency low of 8 Hz is lower than any other call recorded. The frequency difference distribution is most comparable to the downsweep. The duration range, from 0.3 to 1.1 s, has two peaks, 0.4 s and 0.7 s, as was seen in the upsweep. Once again, the limited sample size is probably a factor greatly affecting the apparent range.

Double calls were given a separate category although they are a temporal variation and do not exhibit distinct structural differences. Double calls are two downsweeps which appear to occur as a pair having a shorter intercall interval between the two calls than follows the last of the pair. The second call may overlap the first, and for this reason I believe the calls are produced by two animals. No consistent temporal pattern was maintained throughout any recording in which double calls appeared. A series of double calls exhibiting slight variations in intercall interval are shown in Fig. 15.

The ninth structure sounds very similar to the release of bubbles underwater (Fig. 16). It is unlikely this is a call, although it may have signal value if it is a by-product of feeding. Bubble-like sounds were recorded only six times. The sound is generally broadband, with a FD of 7 to 39 Hz overall, and has a moderate duration, 0.6 to 1.0 s. FH ranged from 19 to 73 Hz and FL ranged from 16 to 40 Hz.

Thuds and slams are another miscellaneous sound that cannot be classified as a call. These are very broadband and short duration sounds that are probably produced differently from any of the other calls or sounds previously described. As is suggested by the terms, a thud is a lower frequency sound than the slam. The slam frequently had components that reached up to 1 kHz. These were not necessary for characterization and were not measured. The maximum recorded value was 200 Hz. The audible difference is similar to the difference between hitting a wooden surface with a closed fist (a thud) versus an open hand (a slam). The two were placed in the same category due to the subjective determination required to classify sounds that seemed to be intermediates during the original measurements. The plot for FD versus FI illustrates the difference between the two revealed in the relationship between those two parameters (Fig. 27). There is a mode for FH at 90 Hz, at 15 Hz for FL, and at 75 Hz for FD from an evening recording of thuds that were very stereotypes (Fig. 16). Although the range of duration is 0.2 to 0.8 s, 68% of the thuds and slams were 0.3 s long.

The final structure, number 11, is a rumble (Fig. 16). The rumble is a frequency and amplitude modulated long call. Initially the call has no harmonic structure, but as the intensity increases harmonics are apparent. This call was encountered rarely, as listed

in Appendix 2, however, when produced, it was several seconds long. The frequency range for the rumble is 10-30 Hz, and there may be second and third harmonics. The rumble loses the frequency modulation with distance and may be confused with a distant blue whale call. Therefore the only rumbles examined were those occurring when the source could be confirmed. The rumble was recorded during only five of the sessions but was present during other sessions that have not been detailed here (Appendix 2).

Following classification of the structural groups I ran a stepwise discriminant analysis using an SPSS computer program. Problems with the SPSS program apparently caused deletion of some of the data. The procedure was conducted despite violation of the normal distribution and equal variance assumptions for multivariate analysis. For these reasons, the results are only of heuristic value in suggesting the importance of variables collected during this study for separating the different structures whose variability may be important biologically if not statistically.

The variables given for analysis were FI, FF, FD, duration (TD) and the rate of frequency change in a call, R, calculated by dividing the frequency difference by the total duration yielding a rate value (Hz/sec). The purpose of including all these parameters was to determine which combination of parameter differences would be adequate to distinguish among the structures. Intercall interval was not entered since the interval may have been dependent on the number of animals calling, and not the call structure for most of the structure types.

For the first analysis all of the downsweeps were grouped together. Three discriminant functions were produced and two were used for plotting

centroids (Table 4). FL was most important in the first function and FH was most important in the second. The order of variable entry in the stepwise procedure was determined by the increase in Rao's V, a statistic which maximizes differences between groups taking the intra-group variation into account. FL entered the function first and therefore provides the best means of discriminating the structures. R appears as a positive value in both the first and second function and was the second variable entered in the analysis. This result indicates the combination of FD and TD into a rate variable provides more distinguishing capacity than either variable separately. FI did not enter until the third phase. FD only adds discriminating power in the second function and TD is of little significance in either. Plots constructed by using the first and second discriminant functions provide a visual comparison of the difference between the group centroids which should be distinct from all other group centroids (Fig. 28). The test of the discriminating power is to reclassify all cases into groups using the discriminant function. Reclassification was correct for only 44% of the calls, however, the results may indicate relationships between the calls. Three structures were classified into their group alone: the constant frequencies call, the tone, and the thud, slam. Downsweeps were placed in their group, group 1 most frequently, but were also placed with all other structures except the tone. The combination call was correctly classified into group 3 for 77% of the calls, but 23% were placed with double calls. The plot of group centroids (Fig. 28a) reveals a close association in the function parameters for the downsweep, constant frequencies call, combination call and the double call. Because of the similarities discussed under each structure it is not surprising that these structures appear clustered.

The discriminant analysis was repeated using two groups for the downsweep, dividing $s = 1$ at $FI = 40$ Hz. For this run, four discriminant functions were produced. FF was loaded most heavily in function I, while FI was loaded most heavily in function II (Table 4). The correct classification percentage was higher: 50%. Again, only the constant frequencies call, tone, and the thud/slam category were correctly classified for 100% of the calls. The higher downsweeps ($FI > 40$ Hz) were not classified correctly for 60% of the calls. However, the lower downsweeps ($FI \leq 40$ Hz) were classified correctly for 52% of the cases, while 38% were placed in group 2, the constant frequencies call. The plot of group centroids (Fig. 28b) appears to be reversed, and the downsweeps are well separated. The high downsweep is closest to the thud/slam category.

Session Analysis

The analysis of the entire file of calls defined the overall variability in call types. The second phase of the sound analysis was an examination of the better recordings to determine the distribution of each sound in the different recording sessions. I transformed the actual number of each structure to the percentage of that structure for the total session to facilitate comparison of sessions with different numbers of calls. Both the number and the percentage are presented in Table 5. Sessions from the same sighting are grouped. The sessions include recordings of single animals, pairs of adults, an adult and calf pair, a pair of adult animals with a calf, two pairs, and three or more dispersed animals. The behavioral category for each sighting appears in Appendix 2. Two sessions were recorded at night to document thuds and distant calls.

The occurrence of downsweeps and constant frequencies throughout the sessions indicates their relative importance in the repertoire. The thuds and slams occur during several sightings. They are primarily represented by the special night session and the recording during high seas (B=5) when several fin whales were in the area.

Because the downsweep was the predominant call, it was examined for inter- and intra-session variability which could be related to individual or contextual variation. The previous structure analyses of all the downsweeps recorded from this sample of the St. Lawrence population provided the basis for comparison. Scattergrams revealed no different underlying covariate relationships for any recording session. R, the rate parameter, covaried with FI as it had for the total file of downsweeps, but the relationship had a correlation coefficient of 0.7 or more ($r^2 = 0.5+$) for 13 of the 18 sessions for which R was calculated. The positive correlation coefficient indicates R increased with increasing values of FI, however, this relationship was strongest for the low frequency downsweeps ($FI \leq 40$) and did not always exist for high downsweeps if examined separately.

Histograms were used to visualize variation in range and modes within and between sightings. Although the number of repeated recordings of the same number and class of whales were few (e.g., one adult, an adult and calf) there were some suggestive trends. Variation in downsweeps was least for solitary animals, regardless of the number of calls recorded (Fig. 29). Reduction of the one long solitary fin sighting into consecutive sessions illustrates the slight intra-session variability (Fig. 30). Comparison of the parameters for the individuals reveals no apparent differences which might indicate individual variation (Fig. 29). However, both whales lacked distinctively different dorsal

fins. Most solitary individuals produced primarily low frequencies. One solitary individual produced only the high frequency downsweep. All of the recordings with only high frequency downsweeps had few calls (range: 3-18).

Variation was greatest in downsweep characteristics for recordings of pairs of adult animals (Fig. 31). However, no distinctly bimodal patterns were apparent in these recordings. Thus there was no indication of individualization. Of course we do not know if one or both of the animals was calling. An adult and calf recorded for two sessions had one session of low downsweeps and one with 31% high downsweeps. The variability may be related to social activity.

An adult-calf pair and another adult (05:52, 05:55, 14 Aug) were observed for over 3 hr. During that time the animals separated, rejoined after 1 hr and then separated again. Ship noise prevented continuous recording but three of the five sessions could be analyzed. The first was recorded after the pair left the adult, who remained in the area. The second was recorded when all three animals were reunited and the third was recorded after the single adult left and the adult-calf pair remained in the area. Therefore, this sighting potentially has both individual and contextual variation.

As shown by the FH, FL histograms (Fig. 32), the first session had a lower range of FH values; the second had two peaks, one corresponding to the peak of the first session, and one corresponding to the peak of the third session. FL values do not show a similar shift. If the FH mode of the first session is attributed to the solitary animal, and the FH mode of the second session attributed to the adult-calf pair, we would expect a bimodal distribution when both were in the area. The second session is suggestively bimodal. The call duration and frequency

difference tended to increase throughout as FH increased (Fig. 33). Finally, if we compare consecutive subsessions for the solitary whale (Fig. 30) and for the pair discussed previously (Fig. 34), we see no similar shift in FH values.

All of the sessions examined had limited TD ranges and the mean values were very similar as a result. Intercall interval range varied greatly. However, values were clustered below 12 s for all sightings as was apparent for the entire file of calls (Fig. 35). The greatest and most consistent variation occurred in the frequency parameters.

The coefficient of variation was calculated for the frequency parameters of each session and subsession (Appendix 1). These values were compared to the coefficient of variation for the corresponding parameter for the entire file of downsweeps. The coefficient should be smaller within sessions than for the total file if individuals consistently produce downsweeps that differ from other individuals' downsweeps.

FD had the highest coefficient of variation for the entire file and for 83% of the sessions. FH had the lowest coefficient of variation for the total file, but was the intermediate value for 58% of the sessions. FL had the lowest coefficient of variation for 58% of the sessions. Closer examination of the sessions revealed inconsistencies within sightings for the relative variation of FH and FL (see Appendix 1). Therefore, either could be important. I produced a series of scattergrams to examine the range of FH, FL, and R for each tape session. The output was a bar graph for each parameter. It was apparent from these bar graphs that the range of intra-session values overlaps considerably with inter-session values, even for FH (Fig. 36 and 37). In addition there are no distinct clumps of values in multiple animal sessions that might correspond to individual ranges.

Figure 11 illustrates the dorsal fin variation for the individuals recorded and photographed and indicates which sightings are believed to be the same animal or animals. Comparison of recordings for these animals did not reveal any pattern. Few of these recordings are of solitary individuals and more than one animal may have been calling. In addition, pairs may not produce individualized calls when with a 'known' companion.

Since no single parameter indicated individual variation I ran another SPSS discriminant function analysis using sessions as the a priori groups. Again, the assumptions of normality and equal variance were violated. The purpose of the run was primarily to examine the group centroids plot for clusters that represented the same sighting. Step-wise discriminant analysis to maximize Rao's V was conducted to determine if functions could be defined which would separate the calls. The variables entered were FH, FL, FD, R, and TD. Group centroids were not consistent within sessions of the same sighting of the solitary individual. Therefore little can be inferred about the other session results. A second discriminant analysis was conducted on only six sessions to reduce the group variances and improve the hypothesis testing capability of the analysis. The discriminant functions did produce different group centroids, but the functions could not correctly reclassify a majority of the calls.

DISCUSSION

Observations

During this study we recorded the occurrence and activity of fin whales in order to document any patterns or changes in behavior which might be correlated with sound production. Fin whales occurred singly most frequently. A comparison of July, August, and September illustrates a marked increase in the occurrence of larger groups of whales. This trend peaked in mid-September. There was also an increase in the number of solitary sightings, indicating an overall increase in the activity of fin whales in this particular area. No fin whales were sighted near shore or during scans on 22 days with full observation. In comparison, no minke whales were observed on 10 of the days with full observation. Minke whales were almost always observed singly, while fin whales were frequently in groups. The relative patchiness of fin whale occurrence may be related to group movements through our area.

No diurnal pattern was consistent for all four observation periods. The whales did not seem to move with or against the tide in our area. However, the bimodal distribution for all fin whales (Fig. 8c) indicates the whales may travel when the tidal flow is greatest. Norris et al. (1977) monitored gray whale activity and correlated their movements with the tidal cycle in Magdalena Bay, Baja California. During low tide, the shallow water was a potential hazard and the whales moved into deeper water as the tide fell, presumably to avoid stranding. Norris also found the whales' activity pattern was correlated to tidal movement. The whales fed when the tidal velocity was high and interacted socially during lower velocities (Norris and Wursig, 1979).

Similar studies have been conducted for odontocete populations. Shane (1977) and Irvine et al. (1978) found that bottlenose dolphins, Tursiops truncatus, generally move with the tide, unless they are searching for food. Saayman and Taylor (1979) reported that humpback dolphins, Sousa sp., decrease group movement as the tide rises and increase their feeding activity and resting episodes. Since the baleen whales were not exhibiting feeding behavior in our area of the St. Lawrence, they may have been moving to other feeding grounds between the tides so as to be at a good site during the high tide. This tidal relationship may be the result of prey concentration due to tidal currents. Gaskin (1976) reported that feeding minke whales concentrate their activity in areas with rip tides.

Ship Noise

As presented in the results, ship noise can interfere with the reception of fin whale sounds. However, ship noise was consistently restricted to frequencies above approximately 25 Hz. Therefore it is the higher frequency calls and the initial frequencies of the lower frequency downsweeps which are masked by the ship noise. There is the possibility that ship noise may adversely affect fin whale communication. Although we did not quantify ship and whale interactions, we have noted occasions when whales altered their paths and increased the distance between themselves and a vessel. Calves and adults may reorient to place the adult between the calf and the vessel. However, ship traffic is a continuous constituent of the environment for fin whales in the St. Lawrence River and it is likely they are accustomed to encountering the ships.

Power boat harrassment is an increasing problem. Whale-watching is a growing industry in the St. Lawrence River. Because the fin whale has

more predictable and longer surface times than the minke, and is far more abundant than the blue whale, it will be the baleen species most affected by that industry. Acoustic and physical harassment by power boats may be less continuous than from ships, but no less serious. Other investigators who have studied whale and vessel interactions have indicated that humpback whales alter their behavior when ships approach (Jurasz and Jurasz, 1977). Hudnall (1978) and Herman et al. (1979) reported that Hawaiian humpback whales may avoid areas frequented by humans. Gray whales are an important tourist attraction in their breeding lagoons and along their migration route. Reeves (1976) reviewed the problem of harassment for this species.

Sound Production

Ten of the 11 sound structures recorded from fin whales during this study have been recorded from other species of baleen whales, although all do not appear in the literature. The only call which has not been described is the combination call. The difference between a combination call and a downsweep is very subtle on a sonagram, the most typical method for analyzing whale sounds. The distinction is far more apparent on the RTA screen. I believe more investigators will find the combination structure if they routinely use scale magnification or an RTA. The downsweep and 20 Hz moan are the predominant calls reported in the fin whale literature, and these were the most common calls recorded during this study.

Some investigators have reported whistles, chirps (Perkins, 1966) and high frequency pulses (Thompson et al., 1979). I did not record any sounds similar to these. Close proximity of the whale is believed to be necessary for reception of these low level signals (Thompson et al., 1979). The fin whales in our area frequently were within 200 m of the

hydrophone, but rarely closer than 50 m. Higher frequency pulses and clicks have been recorded for other baleen species (see Thompson et al., 1979 for a review). Therefore it is possible fin whales produce such sounds. Six of the 11 structures I have recorded from fin whales have been recorded from this species by other investigators either in the Atlantic or the Pacific Oceans.

Schevill and Watkins (1962) were the first investigators to positively identify the fin whale as a source of the 1 s, 20 Hz moan. Their continued research on North Atlantic fin whales revealed two downsweep types: the 20 Hz downsweep, described as a sweep from 23 to 18 Hz, and the 40 Hz downsweep, described as a sweep from 75 to 40 Hz (Schevill and Watkins, 1972; Watkins, unpublished data). During this study my early analysis did not reveal a similar dichotomy for initial and final frequencies. There appeared to be a continuous range of values. However, examination of the interaction of frequency variables (FH, FL, FD) revealed a change in concomitant variation near an initial frequency of 40 Hz. My data indicate the higher frequency downsweep has an initial frequency in the 40-100 Hz range, with final frequencies below 40 Hz (Fig. 22). Watkins (unpublished data) has recorded the higher downsweep more frequently than the lower downsweep in the summer months. During this study, 82% of the downsweeps had an FI of 40 Hz or less. Thus the lower downsweep was recorded more frequently and consistently from late July through September. Although recordings of higher downsweeps were made throughout the summer, these recordings consistently had fewer calls.

Northrup et al. (1968) recorded alternating downsweeps of two types in the Central Pacific: a 27-18 Hz downsweep and a 44-18 Hz downsweep. They noted the briefer downsweep was always less intense by 3-5 dB. The

latter may have been a call from a more distant whale, although the difference in frequencies could certainly have been real variations. The briefer downsweeps could have appeared briefer because of attenuation, as shown in Fig. 4. However, the attenuation increases I used to illustrate loss of the real FI were 10 dB increments. In addition the amount of the call that is lost by attenuation would be dependent upon the rise time for the maximum intensity. It is possible that one animal is producing a patterned call alternating frequency and intensity characteristics. A directional recording system is required to determine if one or more animals are calling. An acoustic directionalizer has been designed and successfully used for southern right whale research by Clark (1979).

The constant frequencies calls recorded during this study may fall into two categories. The boundary is not defined by concomitant variation, however. During the sound analysis there appeared to be a continuum of calls of low intensity. Some had slight frequency sweeps (1-3 Hz) while others did not. These were classified as downsweeps and constant frequencies calls, respectively. As was presented in the description of the constant frequencies call, 39% of the calls had FH values of 21-18 Hz and 40% had FL values between 18-16 Hz. This relatively narrow bandwidth is similar to the sustained final frequency bandwidth of downsweeps (see Fig. 4). The shorter duration, lower FH and FL, narrower FD and lower intensity ranges (66-96 dB) indicate at least some of the lower constant frequencies calls may be truncated downsweeps. This truncation may be the result of attenuation, however, many of the constant frequencies calls were not low amplitude calls. These may have been truncated by the whale. Discriminant analysis placed the group centroids for constant frequencies calls closer to low

downsweeps than to any other structure (Fig. 28b).

Patterson and Hamilton (1964) reported sounds recorded in Bermuda from November to March. Their description includes several types of "doublets", two calls with consistent temporal patterns. The pair of calls consisted of a larger amplitude downsweep with FI of 25-28 Hz dropping rapidly to "a steady 20 Hz" and a smaller amplitude "pulse" with a fairly constant frequency of 18 or 19 Hz. The latter call corresponds to characteristics I have observed for the lower intensity constant frequencies call. Patterson and Hamilton also provide the only reference in the fin whale literature to a "140 Hz pure tone". They found the 140 Hz tone associated with doublets when the unseen source was close to the hydrophone. Schevill (1964) identified the fin whale as the source from his study of the species, although he had never recorded the 140 Hz tone. My study confirms the production of tones by North Atlantic fin whales during the summer months. Patterson and Hamilton (1964) measured the source intensity for the tone and stated that it was one-tenth the intensity of the downsweeps. I found the tone to be 5-19 dB less intense than the downsweeps preceding or following. The maximum difference I recorded was, therefore, approximately one-half to one-tenth. Because of the great difference in intensity, the tone is difficult to see on a sonagram when the reproduce level is set for the louder downsweeps; but even at low intensities, the tone was audible. Monitoring the tape during all analyses will assure the detection of tones if they occur.

Cummings and Thompson (unpublished data) have several sonagrams of miscellaneous fin whale sounds. One of these appears to be an upsweep

from 40 to 80 Hz. Their recordings were made in the Gulf of California under social conditions similar to those we observe in the St. Lawrence River. This is the only other recording done in the presence of fin whales which has an upsweep. The relative rarity of the upsweep during this study and the lack of similar sounds during other studies indicates that the call is rarely produced or only used in specific contexts which may not have existed during previous studies. There is the possibility that the upsweep was not produced by the fin whales, but by an unseen source. This is unlikely since the intensity and frequency ranges for all the upsweeps were appropriate for fin whales. The only other possible sources are the minke or the beluga whale. We rarely encountered beluga whales in our immediate area, although they were frequently visible 5-10 km away during scans. Their distant calls were always less intense than those of the baleen whales in the area. In addition, their higher frequency range excludes them as a possibility (Morgan, 1979; Fish and Mowbry, 1962). The minke whale is the only remaining possible source. Upsweeps have not been recorded from minke whales, but we know less about their vocalizations than we do for the fin whale. We did not see minke whales during all the sightings in which we recorded upsweeps, but they were in our area frequently. Therefore this possibility cannot be completely excluded. It is unlikely that minke whales could produce the lower range of upsweeps (20-24 Hz) since their lowest downsweeps reached 60 Hz.

Doublets, or pairs of calls with a consistent temporal relationship have been reported by several investigators and attributed to fin whales (Kibblewhite et al., 1967; Northrup et al., 1971; Cummings and Thompson, unpublished data). Only Cummings and Thompson were observing fin whales during their recording session. While the other references

appear to be recordings of calls similar in duration and frequency to blue whale calls I recorded in the St. Lawrence River, the calls Cummings and Thompson present do not correspond to any calls I recorded. The double calls I recorded were downsweeps which had only a temporary temporal association. Therefore, I believe the calls I designated as double calls are produced by two individuals which may or may not be calling in response to each other. Some of the calls overlapped temporally, confusing the initiation and response relationship. Additional data is required to accurately assess the relationship.

The last structure which I recorded that has been recorded by other investigators studying fin whales is the rumble. Watkins (unpublished data) associates the rumble with awareness of the research vessel or an unexpected situation. My data indicate the rumble may be agonistic as it was produced during the extended 31 July sighting of an active adult pair joined by a calf. During the sighting only intermittent higher downsweeps were produced along with a waver and an upswEEP. The rumble began when the two adults entered our observation area and ceased when they separated. The less active adult was joined by a very small calf which stayed next to "her" flank for the rest of the sighting. The rumble continued to appear intermittently throughout the sighting whenever the second adult joined the adult-calf pair. There was no obvious avoidance behavior by the adult-calf pair, however, all three whales blew together, although not simultaneously, during their final respiratory series in our area. The rumble was not present following their disappearance.

The term rumble has been used to describe low frequency-modulated calls produced by gray whales (Fish et al., 1974; Cummings et al., 1968).

Eberhardt and Evans (1962) noted the rumble only once, when two gray whales passing out of a lagoon encountered another pair entering the lagoon. Considerable surface activity was observed but unfortunately was not described.

Many of the call structures produced by fin whales are also produced by other baleen whales, although the frequency ranges are generally different. In addition, the calls which I recorded in the St. Lawrence that had not been recorded previously in the presence of fin whales are present in the repertoires of other baleen whales. The only exception is the combination call already discussed.

Species in the family Balaenopteridae have numerous similarities in their call structures. The minke produces a downsweep of higher frequency range (130-60 Hz) and shorter duration (0.2-0.3 s) than those of the fin whale (Schevill and Watkins, 1972; Edds, unpublished data). Winn and Perkins (1976) recorded "thump trains" from minke whales. Thompson et al. (1979) hypothesized that the thump trains have potential signature information. One series of thumps, Fig. 2b in that paper, are very similar to the thuds I recorded during high seas with several fin whales in the area. The thump train by minke whales is of higher frequency in all cases shown.

Byrde's whale, Balaenoptera edeni, produces upsweeps, downsweeps and wavers (Cummings and Thompson, unpublished data). These calls may also occur in the annual song of the humpback whale (Payne and McVay, 1971; Winn and Winn, 1978).

The blue whale was recorded in the St. Lawrence River during this study. The long low-frequency calls (15 Hz, 13-15 s) are most similar to the "long 20 Hz moans" recorded at SOFAR stations with no known source (Weston and Black, 1965; Kibblewhite et al., 1967). The call

is similar in frequency range and duration to the rumble of the fin whale, but does not exhibit frequency or amplitude modulation. Other investigators have recorded long low-frequency moans from Pacific blue whales (Cummings and Thompson, 1971; Cummings and Thompson, 1977).

Species in the two remaining families of baleen whales also produce calls similar to those I have recorded from the fin whale. These will be reviewed briefly.

Cummings (1972) described belches as the predominant sound produced by southern right whales in Patagonia, Argentina. However, in 1974 Cummings et al. reported primarily bellows and moans of rising pitch. A waver is included in their sonagrams. Recent research on this species has documented the occurrence of upsweeps, downsweeps, wavers, split calls, bubble sounds and slams (Clark, personal communication).

The rarer northern right whale, E. glacialis, apparently has a similar repertoire, although it has not been recorded as frequently (Thompson et al., 1979). Schevill and Watkins (1962) recorded a variety of wavers.

Recent recordings by ONR's Project Whale in the Arctic have identified upsweeps and downsweeps from the bowhead, Balaena mysticetus, using a directionalizer designed by Clark (Clark, personal communication).

The last species which produces calls similar to those I have described for the fin whale is the gray whale. In addition to the rumble already discussed, the gray whales produce wavers (Asa-Dorian and Perkins, 1967; Cummings et al., 1968), and bubble-type sounds which are very similar in both frequency and duration to those recorded during my study on fin whales (Cummings et al., 1968).

Because of the number of similarities between most of my recordings and those reported for fin whales, I feel confident that I have properly

identified the source. As Thompson et al. (1979) discussed, cetacean field work is difficult at best and the sound source is generally inferred. Minke, fin, and blue whales are present in the St. Lawrence River. The humpback whale is an occasional visitor. The only other baleen whale species which might have been in the area is the sei whale, Balaenoptera borealis. We have never positively identified this species and none of the recordings I used were from "suspicious" animals. The right white lip, dorsal anterior chevron, and larger size of the fin whale were characteristics we used for positive identification of the species.

Thompson et al. (1979) provided a classification of baleen whale call types which was presented in the introduction. The calls which I recorded fall into three of the four categories. The downsweep, upsweep, constant frequency call, combination call, waver, split call, and the double call, are all considered to be means. The tone would be classified as a cry. Thuds and slams would be classified as thumps and knocks because of their wide bandwidth and short duration. The last category, clicks and pulses, was not represented by any of the calls recorded from fin whales in the St. Lawrence River.

Context

The behavioral codes we assigned to each sighting were designed for use as summaries of context for sound production. Comparison of Appendix 2 and Table 5 reveals no apparent relationship between behavioral context and the sounds produced. Whales which we designated as active by their surface behavior were not necessarily active acoustically. Whales which passed through the area on a straight course often vocalized. Solitary whales may produce more sounds than a trio of whales. During this project, the solitary whale that was very vocal may have been in

acoustic contact with another whale, or actively advertising its presence or position. Intensity variations during this particular recording may indicate the presence of an unseen distant source. However, it is difficult to designate one intensity range as a near whale and the remaining calls as a far whale when there is no obvious break in the entire range. In addition, we cannot rule out individual variations in call intensity.

No call or sound (e.g., bubble sounds) was limited to only active sightings or to sightings involving calves or pairs. The call most frequently recorded during the study, the downsweep, also constituted the most frequent call per sighting. These results indicate that if a North Atlantic fin whale vocalizes it is likely to produce downsweeps. The other call types and sounds (e.g., constant frequencies, waver, thud and bubble) are comparatively rare. Therefore it is likely the downsweep is important for species recognition. The other calls and structures may only be produced in specific contexts not readily identifiable by a surface observer. The lack of calls early in the season suggests that call rate may be dependent upon the number of animals in the area. The question then is how do the whales know how many whales are in the area? It is possible that downsweeps are produced intermittently for short periods until calls from other animals are heard. The animals may increase the call rate as a response. The scattergram of call duration versus intercall interval was usually below 12 s. This value agrees with the values given in the literature for the long trains of calls recorded from SOFAR stations.

The downsweep may be considered a key sign as defined by Schleidt (1973). A key sign is the product of a behavioral event of likely communicative function. Schleidt categorizes the key sign by its

discontinuity or continuity with other possible key signs in the repertoire. The discontinuous key sign is one that is distinct from any other key signs, has little variability, and has no association with motivational state. If one assumes the whales recognize the lower downsweep as a call distinct from the higher downsweep, the two may be considered as different key signs. The lack of variation in the lower downsweep, as well as its occurrence in nearly all of the recordings, indicates it is a discontinuous key sign. The higher downsweep appears to be correlated to social activity, and should be classified as a continuous key sign which may vary with motivational state. Key signs frequently have typical repetition rates (Schleidt, 1973). The fin whale literature describing low frequency downsweeps stressed the consistent pattern of repetition rates over periods of an hour or more (Walker, 1963; Northrup et al., 1971). For fin whales, high repetition rates for downsweeps may serve to separate the sounds from the noise, facilitate localization or achieve a cumulative effect over time. Watkins (unpublished data) observed that the downsweep patterns occur during the winter breeding season. This apparent seasonality suggests a functional significance similar to the higher repetition rates of male songs during avian breeding seasons (Thorpe, 1961).

The significance of the lower versus the higher downsweep for species recognition is also an important consideration. Emlen (1972) discussed species recognition and individual variation as they occur in passerine birds. Species recognition was dependent upon the most constant and unvarying features in the species repertoire. Although we probably do not know the entire repertoire of the fin whale, the most unvarying characteristics are those related to the lower downsweep. Since this call was the principal constituent of solitary whale recordings

I believe the lower downsweep may be most important for species recognition. Examination of the FH, FL scattergrams illustrates the relative lack of variance particularly in FL. This is particularly interesting since the FL values are generally below wave noise and shipping noise as well (Urlick, 1967; Wenz, 1964). Therefore the most consistently produced parameter is also the one most likely to be consistently received.

Recognition of individual birds is usually based on song characteristics which vary within a population but do not vary for the individual bird (Emlen, 1972). In addition, individual variation is most likely to be coded in a few parameters which exhibit little overlap between individuals (Schleidt, 1976). No such parameter or combination of parameters was discovered for the fin whale downsweep during this study. However, the lack of numerous known solitary individuals hampered this phase of the analysis. Multiple animal sightings may not have contained individualized calls if the animals "knew" their companions and produced calls as a social exchange. Only one series of sessions indicated variations in the mode(s) for FH values which corresponded to the presence of known individuals. The separation and subsequent reunion of the animals (14 August, 05:55 pair, 05:52 single) provided a series of contexts in which one would expect to see individual variation. Repeated sightings with recordings of this nature are required.

Motivational state is revealed in the variabilities in an individual bird's song (Emlen, 1972). Since fin whale calls do not exhibit the same stereotypy of bird song, it is difficult to assess what variabilities of the higher downsweep are individual versus motivational. It is also possible that both factors are interacting. However, the high degree of overlap among the limited number of sightings I examined indicates that the differences are not individual. If we assume motivational

variation, it is interesting to examine recordings where the animals appeared to be agitated or excited for extremes in the higher downsweep parameters. The implication here is that higher downsweeps, may correlate with higher levels of arousal. For example, compare the following: 31 July pair and calf when the rumble was produced (Fig. 37 code 4,5); 18 August pair chased by a power boat (Fig. 37 code 24,25); and the 13 September group of fin whales exhibiting splashing and breaching (Fig. 37 code 36,37,38). Only two of the above have high ranges for FH values. The pair chased by the power boat did not produce high FH values. This may be attributed to the interference caused by the boat's noise; however, most of the calls were produced when the power boat was idling. In addition high FH values were recorded in other sessions (e.g., Fig. 37 code 18,30,43). The latter, number 43, is a solitary individual sighting. Therefore, we cannot correlate high downsweeps only with aroused states as determined by the observer.

The variable which proved to be the best predictor of downsweep types is the number of whales in the area. Even this was not always an accurate indicator because one solitary whale produced high downsweeps. As Payne and Webb (1971) discussed, our determination of a whale's social status (e.g., solitary versus paired, etc.) is defined by physical proximity rather than acoustical interactions. Animals spread over several kilometers may be part of a herd which is a social unit, and the sounds produced by these apparently solitary individuals may be social in nature. The marked increase in call rate for some of the sightings with greater numbers of individuals indicates that more sound is produced when animals are closer. Again this may be related to motivational state or a desire to maintain close contact. Recordings of groups did not necessarily have calling rates that were multiples of

solitary individual call rates. Of course it is not likely that all of the animals in a group call continually.

The final variable which may influence the type of sound recorded is the sex or reproductive state of the caller. A mature male may produce a different call from an immature male or mature female. The difficulty of identifying the caller and positively identifying the sex of the caller has prevented the collection of data which might answer these questions. Watkins believes the patterned pulses (or downsweeps) recorded during the winter reproductive season are not produced by the largest animals of a group, which Watkins suggests are females. My recordings in the presence of an adult and calf include low and high downsweeps, although the low are predominant. One may speculate that the adult is a female, but one could not infer the sex of the calf. It is likely that the female vocalizes but whether her calls are different from those produced by the male is a matter for conjecture and future research.

The study of animal communication requires an initial definition of the species repertoire. Once the repertoire is known, the variability for each call type must be known before any study of seasonal, geographic or individual variation can be investigated.

This project was undertaken to record the repertoire of the fin whale in the St. Lawrence River in the summer months. During this time the animals are feeding prior to the winter reproductive season which presumably occurs in more southern areas (Tomilin, 1967). Although an attempt was made to examine downsweeps for individual variation, the intent was to document variability for comparison with North Atlantic fin whales during the winter season and with fin whale populations from other geographic area. The variability observed in the St. Lawrence River

appears to be greater than that reported by any single previous investigator, but the differences are easily attributable to the comparative intensity of this study on a daily basis over a period of three months. It is hoped other investigations will attempt to monitor activity and sound production of undisturbed fin whales wherever possible. The results of such studies will permit us to evaluate the role of sound production in their daily and seasonal activities.

Table 1 . Summary of computer analyses.

GROUP(s)	SPSS PROGRAM ¹	VARIABLES ²
Total File	FREQUENCIES (Range)	FI, FH, FL, FF, FD, TD, ICI, IN, S
	SCATTERGRAMS	ICI vs. TD
Structures (1-10)	FREQUENCIES (all statistics)	FI or FH, FL or FF, FD, TD, ICI
	SCATTERGRAMS	F's vs. IN; TD vs. IN; FL vs. FH; FD vs. FI; TD vs. FD; ICI vs. TD
	STEPWISE DISCRIMINANT (Rao V Method)	FI, FF, FD, TD, R
Tape Session (1-35)	FREQUENCIES (all statistics)	ICI, IN, S
Structure by Session	FREQUENCIES (all statistics)	FH, FL, FD, TD
	SCATTERGRAMS (S=1, S=2)	FI vs. IN; FD vs. IN; TD vs. IN; TD vs. FD; R vs. FI; ICI vs. TD
Tape Sessions & Subsessions ³ (S=1 only)	STEPWISE DISCRIMINANT (Rao V Method) a. equal covariance group n=6 b. all possible groups n=33	FI, FF, FD, TD, R

¹Nie et al., 1970.²FI initial frequency; FH highest freq.; FL lowest freq.; FF final freq.; FD freq. difference; TD total duration (sec); ICI intercall interval; IN intensity; CALL call number in sequence; TAPE tape session or sub-session; S structure; R=FD/TD.³Subsessions are subsets of sessions to equalize n of cases.

Table 2. Whale sighting data summary from 28 June to 27 September 1979.

Species	Minke	Fin	Blue	Total
A. Sightings ¹	343	241	6	590
Percent of Total	(58%)	(41%)	(1%)	
B. Followed Whales ²	264	114	6	384
Percent of sightings (B/A x 100)	(77%)	(47%)	(100%)	(65%)
C. Straight Upstream	48	27	3	78
Percent of Followed (C/B x 100)	(18%)	(24%)	(50%)	
D. Straight Downstream	56	25	2	83
Percent of Followed (D/B x 100)	(21%)	(22%)	(33%)	
E. Active Whales	25	10	0	35
Percent of Followed (E/B x 100)	(9%)	(9%)		
F. No Pattern	29	6	0	35
Percent of Followed (F/B x 100)	(11%)	(5%)		
G. Recordings	71	35	3	109
Percent of Followed (G/B x 100)	(27%)	(31%)	(50%)	

¹Sightings include whales followed and those sighted in scans. Whales travelling together were counted as one sighting.

²Followed whales were within one km and were visually followed.

Table 3. Summary of acoustic data acquired from 28 June to 27 September 1979.

Species	Recording Sessions (n)	Sessions Analyzed (n)	Mean Session Length (min)	Session Range (min)	Recorded & Photographed (n)
Minke	72	27	13	3-45	31
Fin	35	25	18	3-102	29
Blue	3	1	11	7-15	1

Table 4. Discriminant analysis functions used to plot group centroids for calls and sounds. The relative contribution of each variable is reflected by the absolute value of the function parameter. Relative percent values indicate the degree of discriminating power in the function.

Variable	A ¹		B ²	
	Function 1	Function 2	Function 1	Function 2
FL ³	-2.018	4.957	.751	-3.970
FH ⁴	1.069	-5.824	.289	4.090
R ⁵	.220	.228	-.199	.021
FD ⁶	- .207	1.774	-.126	- .428
TD ⁷	- .119	-2.54	-.052	- .384
Relative percent	87.2	11.0	81.4	12.9

¹ SPSS run with all 10 structures

² SPSS run with downsweeps divided into LOW ($FI \leq 40$) and HIGH ($FI > 40$). All other structures were the same

³ FL lowest frequency

⁴ FH highest frequency

⁵ R rate value $R = FD/TD$

⁶ FD frequency difference $FD = FH - FL$

⁷ TD Total duration

Table 5. The occurrence of call structures in B. physalus recording sessions and subsessions during analyzed sightings. Sessions and subsessions are grouped by the fin whale sighting number.

Tape Code	Animal (s)	Time	Date	Total N	STRUCTURES CODES ¹										
					1	2	3	4	5	6	7	8	9	10	11
1	2A ² C ³ 08:30 10:14 31 July			8	4 50%						4 50%				
2				13	8 62%	4 31%							1 8%		
3				22	18 82%			1 5%	1 5%				1 5%	1 5%	
4				12	7 58%				1 8%	2 17%				2 17%	x ⁴
5				3	3 100%										x
6	2A 06:35 1 Aug.			45	31 69%	8 18%			1 2%		4 9%		1 2%		x
7				47	38 81%	3 6%	1 2%	1 2%		1 2%		1 2%	2 4%		
8	No Source ⁵ 8 Aug.			19										19 100%	
9	No Source 8 Aug.			42 ? ⁶											
10	A 05:27 12 Aug.			16	14 88%	2 13%									
11	A A/C 05:52 05:55 14 Aug.			40	40 100%										
12				12	12 100%										

	Continued	Total N	1	2	3	4	5	6	7	8	9	10	11
13	A A/C 05:52 05:55 14 Aug.	29	29 100%										
14		65	59 91%	3 4%	1 2%	1 2%			1 2%				
15		52	47 90%		1 2%	4 8%							
16	2A 14:26 15 Aug.	5	2 40%	1 20%				2 40%					
17	A A/C 11:05 11:10 16 Aug.	13	6 46%	4 31%	1 8%				1 8%	1 8%			
18		33	26 79%	4 12%		1 3%		2 6%					
19		2	1 50%				1 50%						
20		3	2 67%				1 33%						
21	A 17:00 16 Aug.	47	42 89%	3 6%		2 4%							
22		46	38 83%	2 4%		3 7%			2 4%			1 2%	
23		35	31 89%	2 6%		1 3%			1 3%				
24	2A 12:20 18 Aug.	30	29 97%	1 3%									
25		3	2 67%	1 33%									

	Continued	Total N	1	2	3	4	5	6	7	8	9	10	11
26	A	52	42 81%		3 6%	7 14%							
27	07:35	46	40 87%		1 2%	3 7%		1 2%	1 2%				
28	19 Aug.	47	43 92%	3 6%		1 2%							
29		43 ?											
30	A 07:53 26 Aug.	14	6 43%	3 21%								5 36%	
31	A/C	56	40 71%	16 29%									
32	06:24	18	18 100%										
33	1 Sept.	45	45 100%										
34	2A 2A	50	43 86%	6 12%				1 2%					
35	15:10 15:28	31	29 94%	1 3%	1 3%								
36	1 Sept.	50	47 94%	2 4%	1 2%								
37	4A+ Minke	31	29 94%	2 6%									
	17:45 13 Sept.												

	Continued	Total N	1	2	3	4	5	6	7	8	9	10	11
38	4A 17:45 13 Sept.	31	27 87%	4 13%									
39	A 16:10 15 Sept.	57	32	15 26%		3 5%	2 4%	2 4%	2 4%			1 2%	
40		28	23 82%	3 11%		2 7%							
41		50	40 80%	2 4%		5 10%		1 2%				2 4%	
42		50	41 82%	1 2%		5 10%			1 2%	2 4%			
43		52	46 89%	2 4%		3 6%				1 2%			
44		53	41 77%	7 13%		4 8%			1 2%				
45	A 16:20 A 16:58	60	52 87%	1 2%					1 2%			6 10%	
46	A 17:00 A 17:10 17 Sept.	60	36 60%							4 7%		20 33%	

¹1=downsweep; 2=constant frequencies; 3=combination; 4=tone; 5=wavet; 6=upsweep; 7=split; 8=double; 9=bubble; 10=thud, slam; 11=rumble

²A denotes adult

³C denotes calf

⁴x denotes occurrence of rumble

⁵nocturnal recording

⁶? denotes call too faint to determine structure

FIGURE 1. Map of the research site on the St. Lawrence River. Depth contours indicate proximity of the Laurentien Channel to shore. Modified from Mitchell (1975). T designates Tadoussac, at the mouth of the Saguenay River.

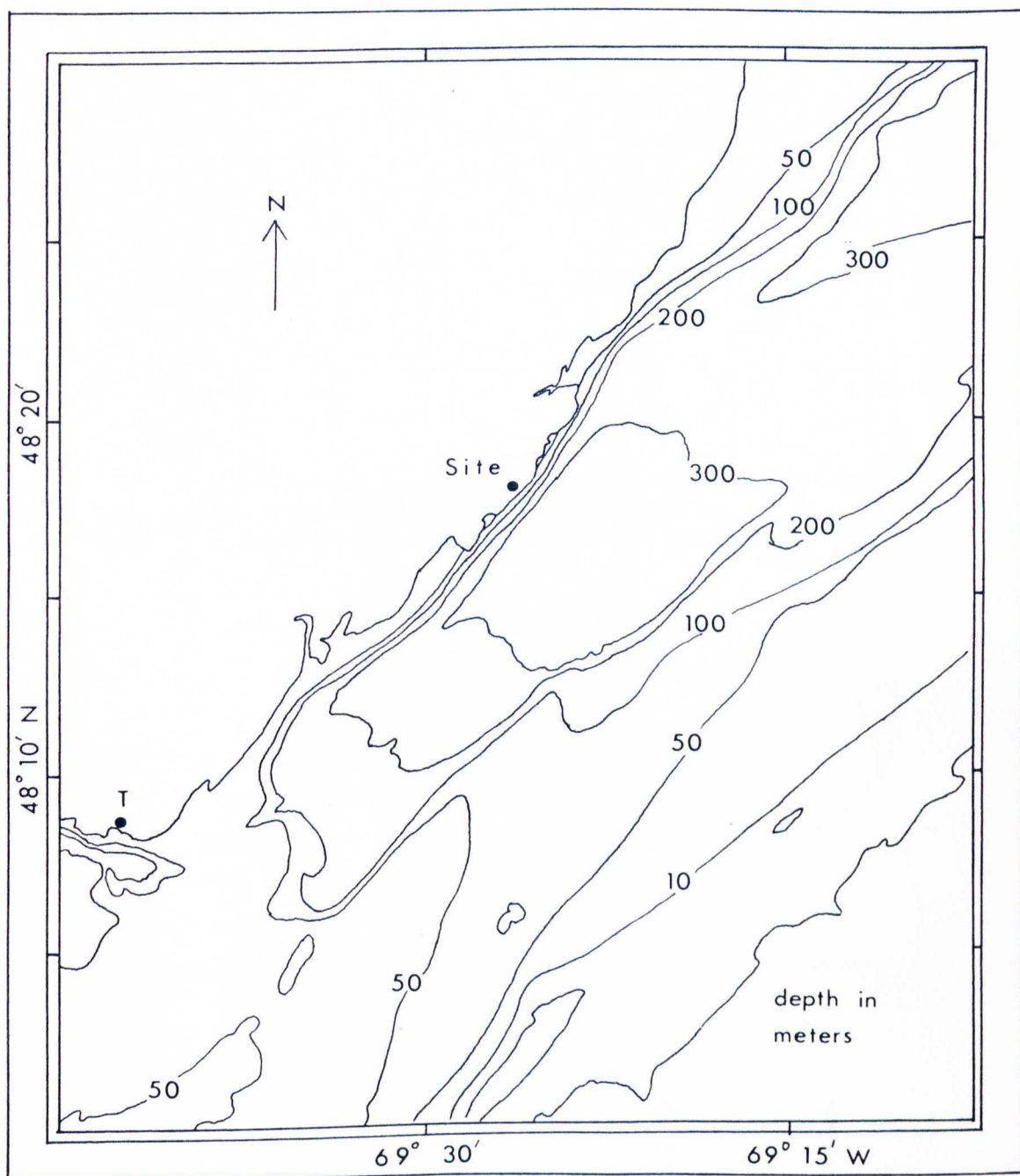


FIGURE 2. Hydrophone-preamplifier and cable arrangement. Nylon line looped to the cable acted as a shock cord. Depth range in meters is given for low and high tide.

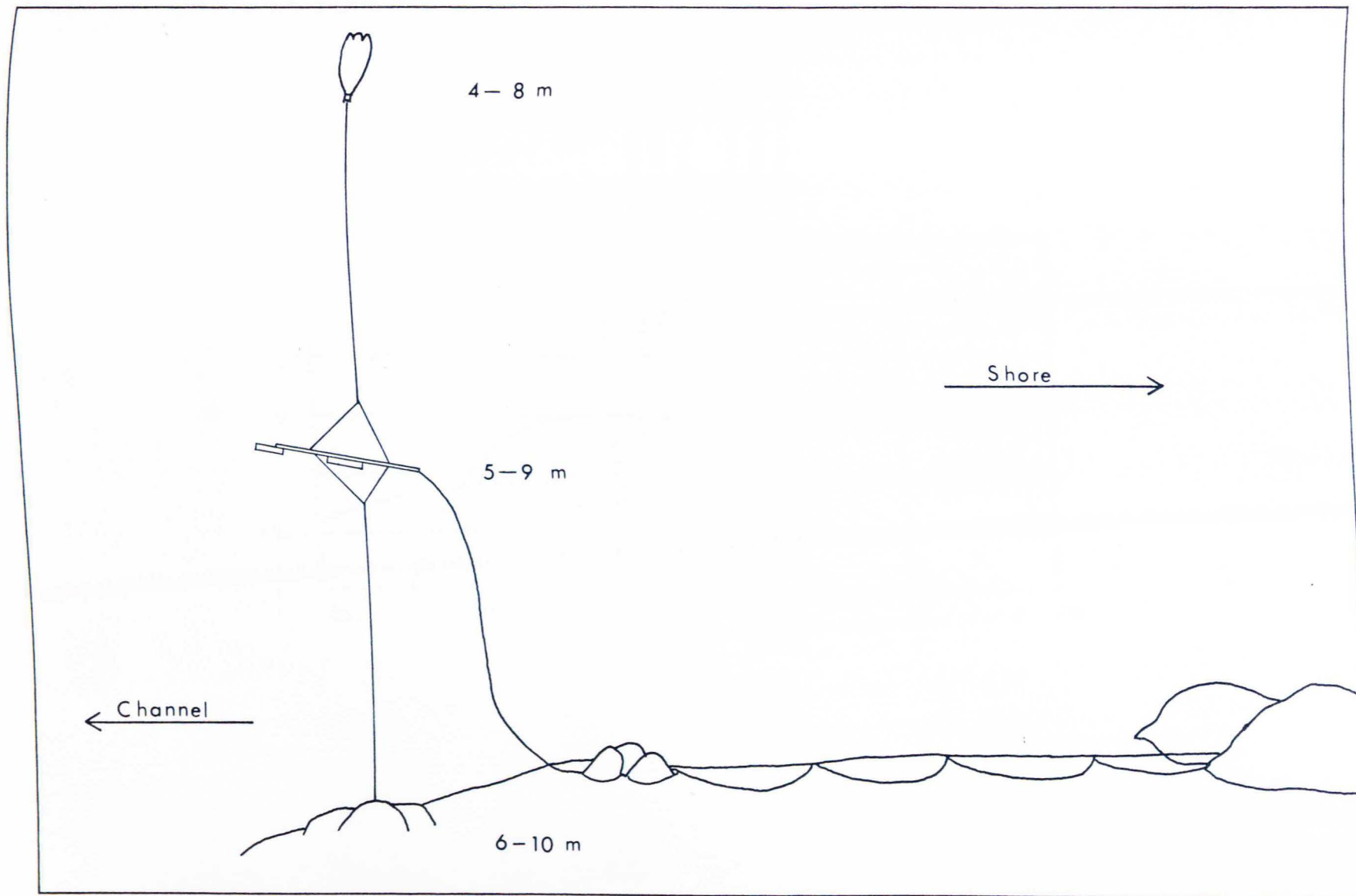


FIGURE 3. Nagra IV SJ response curve and hydrophone system sensitivity. The Nagra curve (N) was determined by inputting a constant voltage over the frequencies shown.

The hydrophone system (HS) consists of the hydrophone-preamplifier and cable. This curve was supplied by the manufacturer, KSP Industries. The sensitivity curve is in dB re 20 μ Pa.

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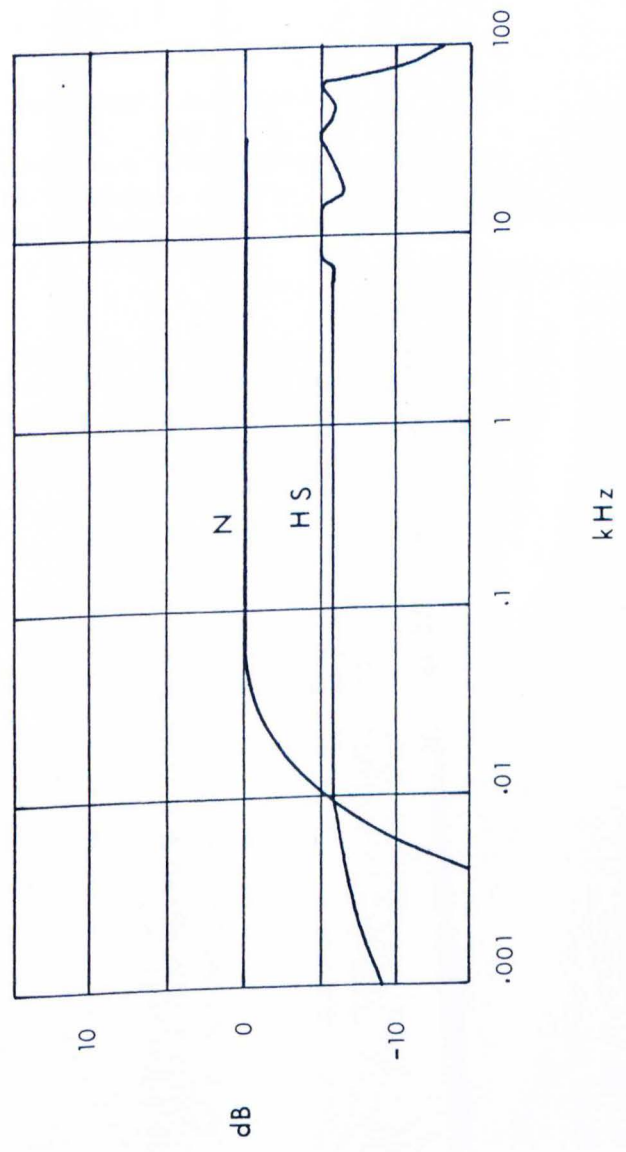
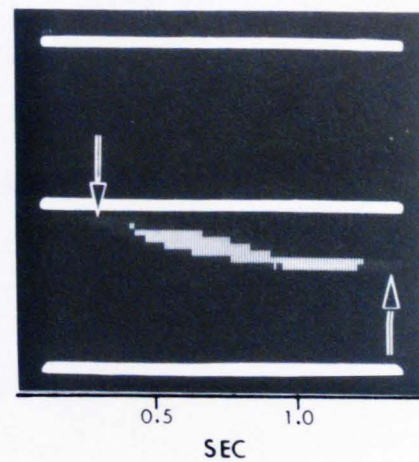
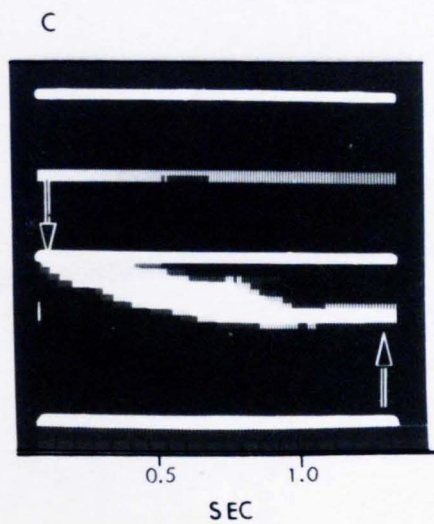
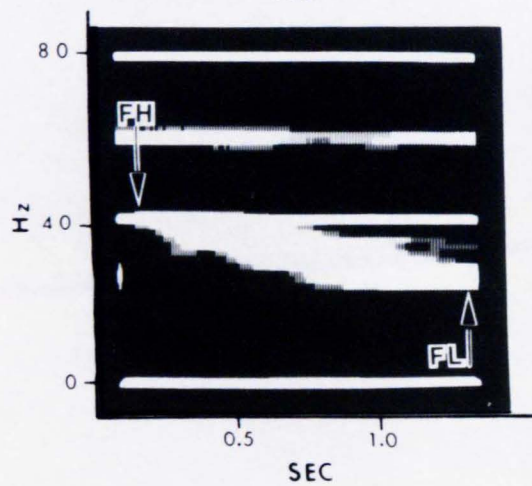
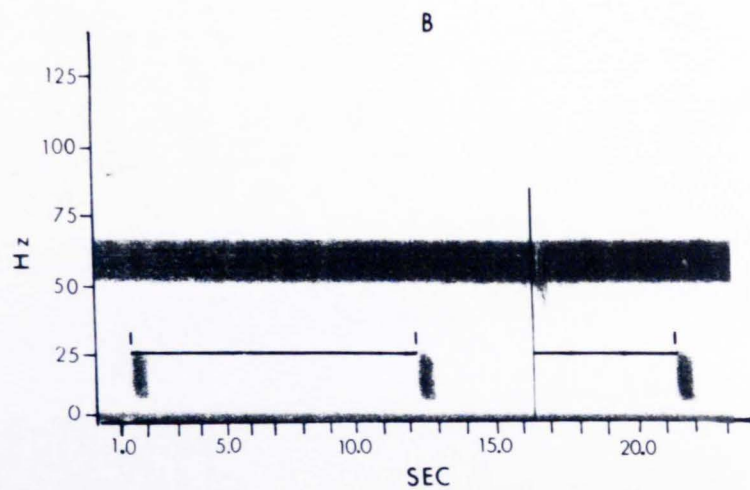
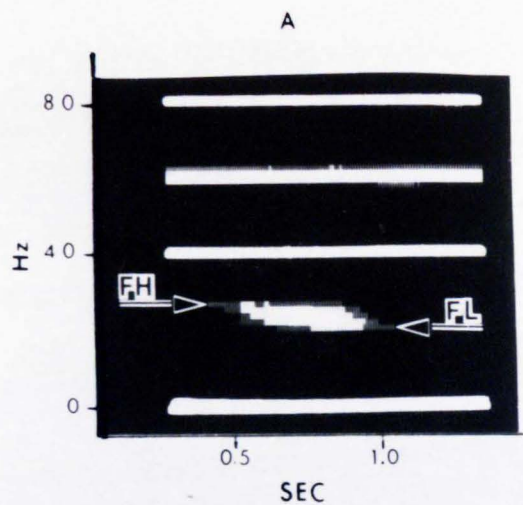


FIGURE 4. Methods of frequency and time measurements.

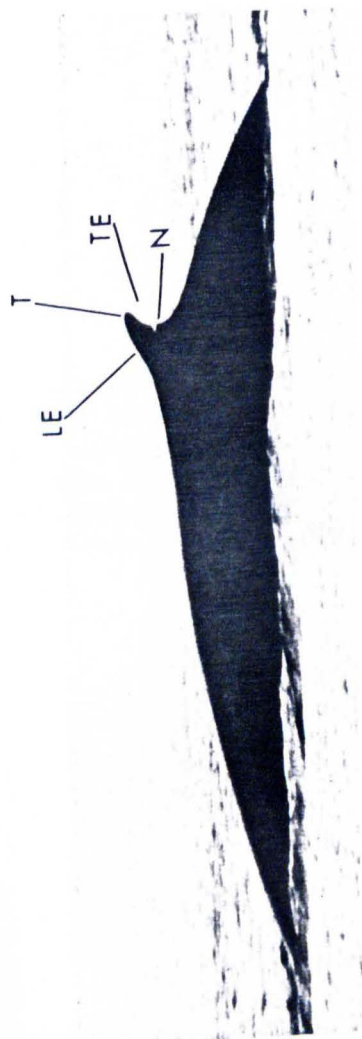
- A. Highest frequency (FH) and lowest frequency (FL) are labelled in the center of the band where they were measured. Duration was measured between these arrows. Photographed from Unigon Scan Converter Screen.
- B. Intercall interval was measured from the beginning of one call to the beginning of the next, indicated by vertical marks on the sonagram. A perpendicular was dropped from the beginning of higher frequency calls to the baseline to facilitate consistent measurement of the interval.
- C. High frequency (FH) and low frequency (FL) value comparisons for the same call with 10 dB increments in attenuation. FH decreases but FL remains the same.



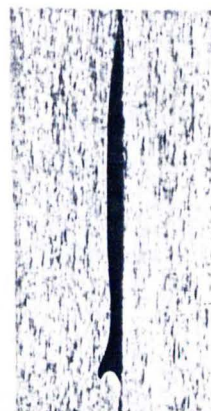
7/1a

FIGURE 5. Distinctive differences in fin whale dorsal fin shape.

- A. Parameters compared include leading edge (LE) shape; shape of tip, T; trailing edge (TE) shape; presence of notches (N); and relative height (e.g., tall or short).
- B. Individual sighted in 1973, 1974, 1975, and 1979.
- C. Same individual as A, sighted earlier in the study. Angle of photograph is not optimal, but distinctive characteristics are visible.
- D. "Plain" dorsal fin. The lack of unusual shape or notches make it difficult to distinguish individuals with this fin shape from each other; but is easily distinguished from A or B.



A



D



C



B

FIGURE 6. Fin whale sightings by day between 28 June - 27 September. Zero sightings on days of partial or no visibility are one block below the zero line for the histogram. Max, maximum possible number; min, minimum possible number; no vis, visibility too poor to observe; part vis, partial visibility.

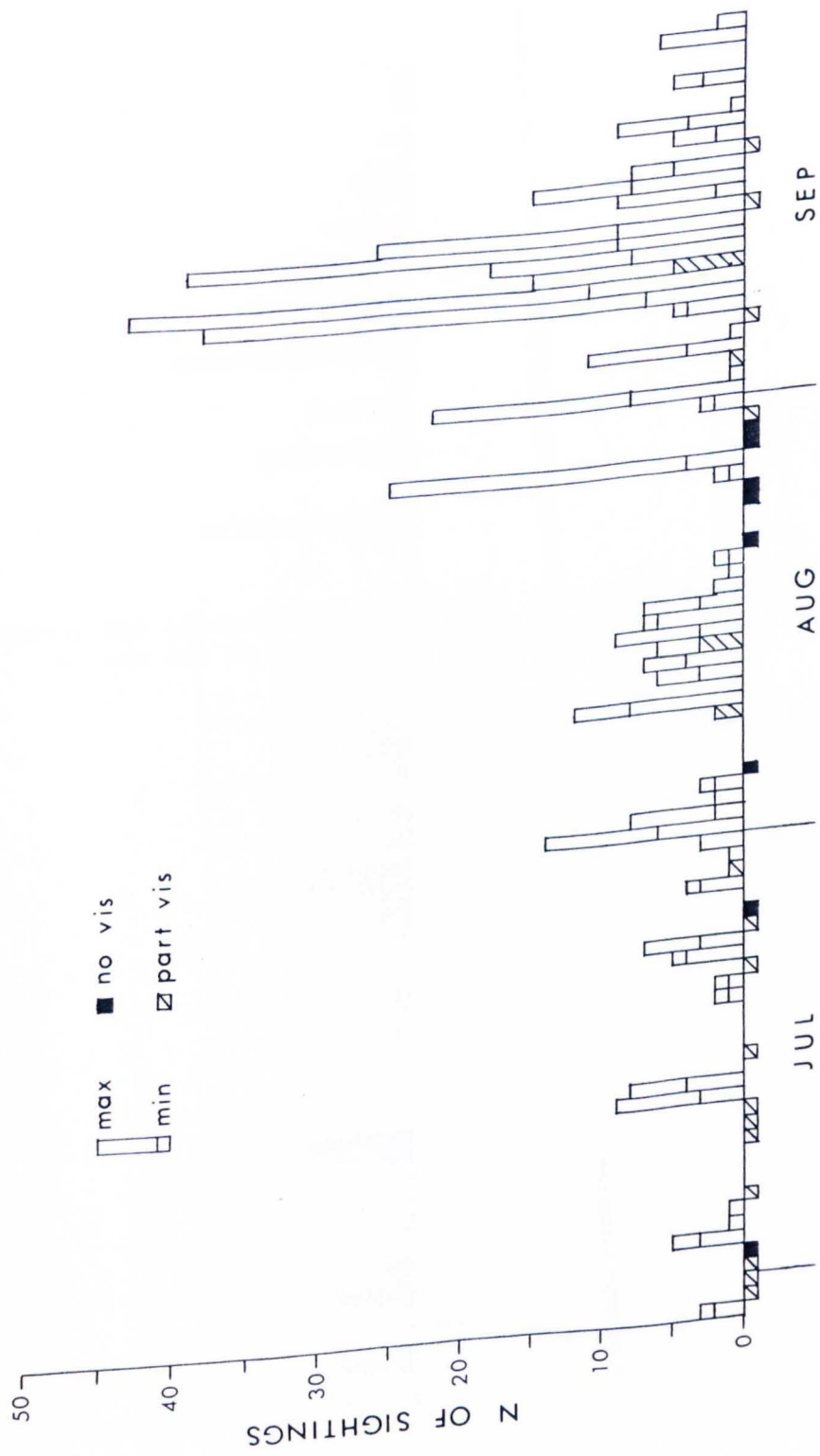


FIGURE 7. Occurrence of individual sightings and groups of different sizes. n , number of fin whales.

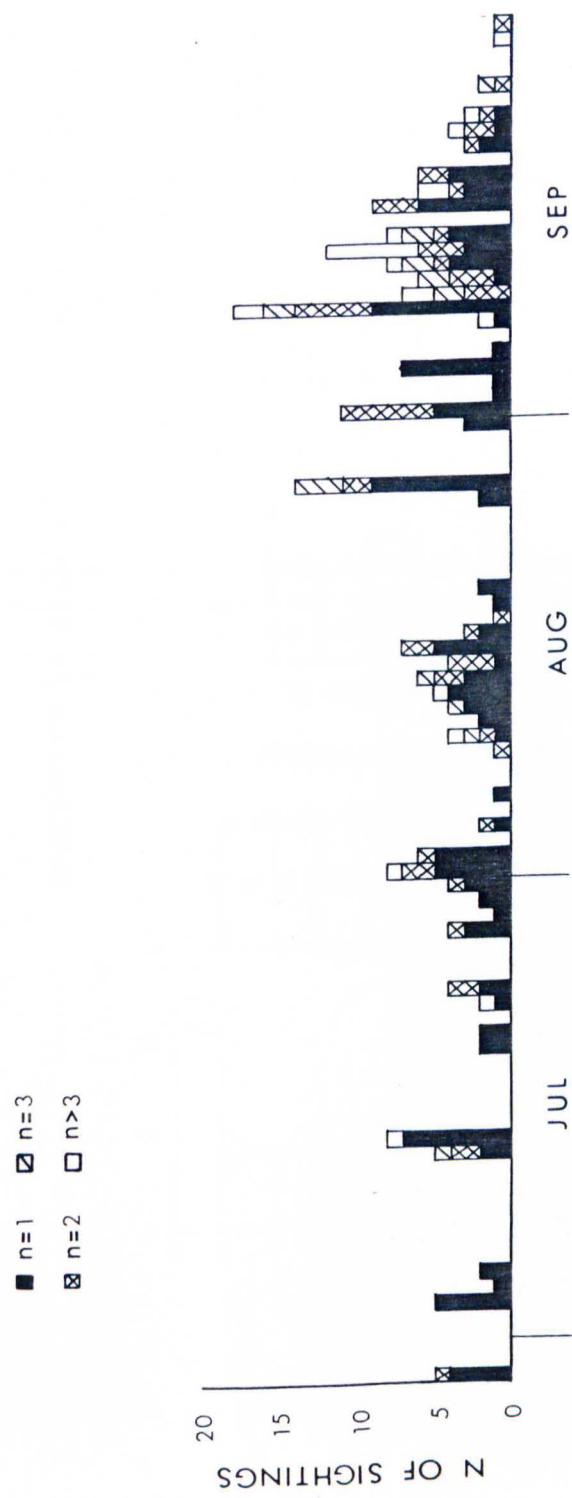


FIGURE 8. Fin whale sightings by hour of the day on a 24 hour clock. The four histograms take day length into account. n, number of sightings.

- A. 28 June - 24 July; 05:00-19:00 h
- B. 25 July - 18 Aug; 05:30-19:00 h
- C. 19 Aug - 16 Sept; 06:00-19:00 h
- D. 17 Sept - 27 Sept; 06:30-18:30 h

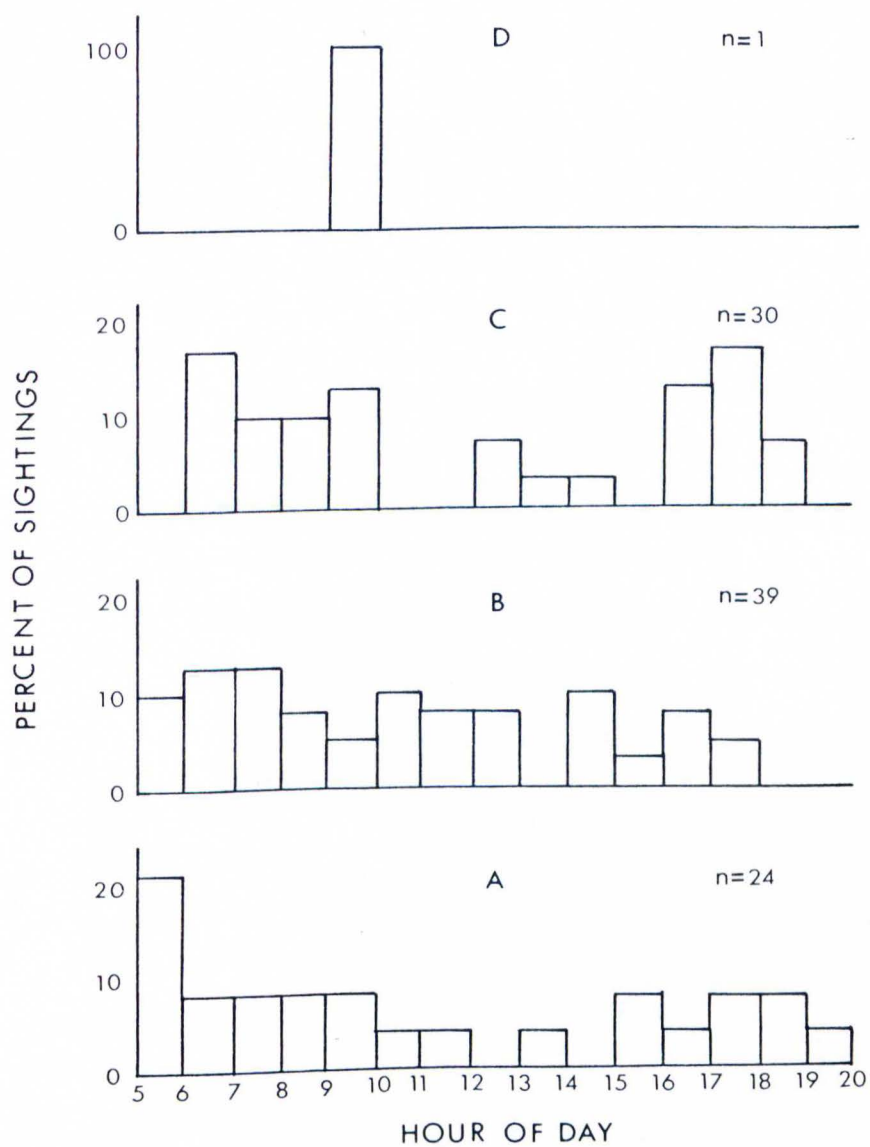


FIGURE 9. Fin whale sightings as a function of tidal cycle.

All sightings were graphed by the time of first observation in one hour increments on either side of the high tide. Both daily high tides are included.
n, number of sightings on each histogram.

- A. Only whales traveling straight upstream.
- B. Only whales traveling straight downstream.
- C. All whale sightings.

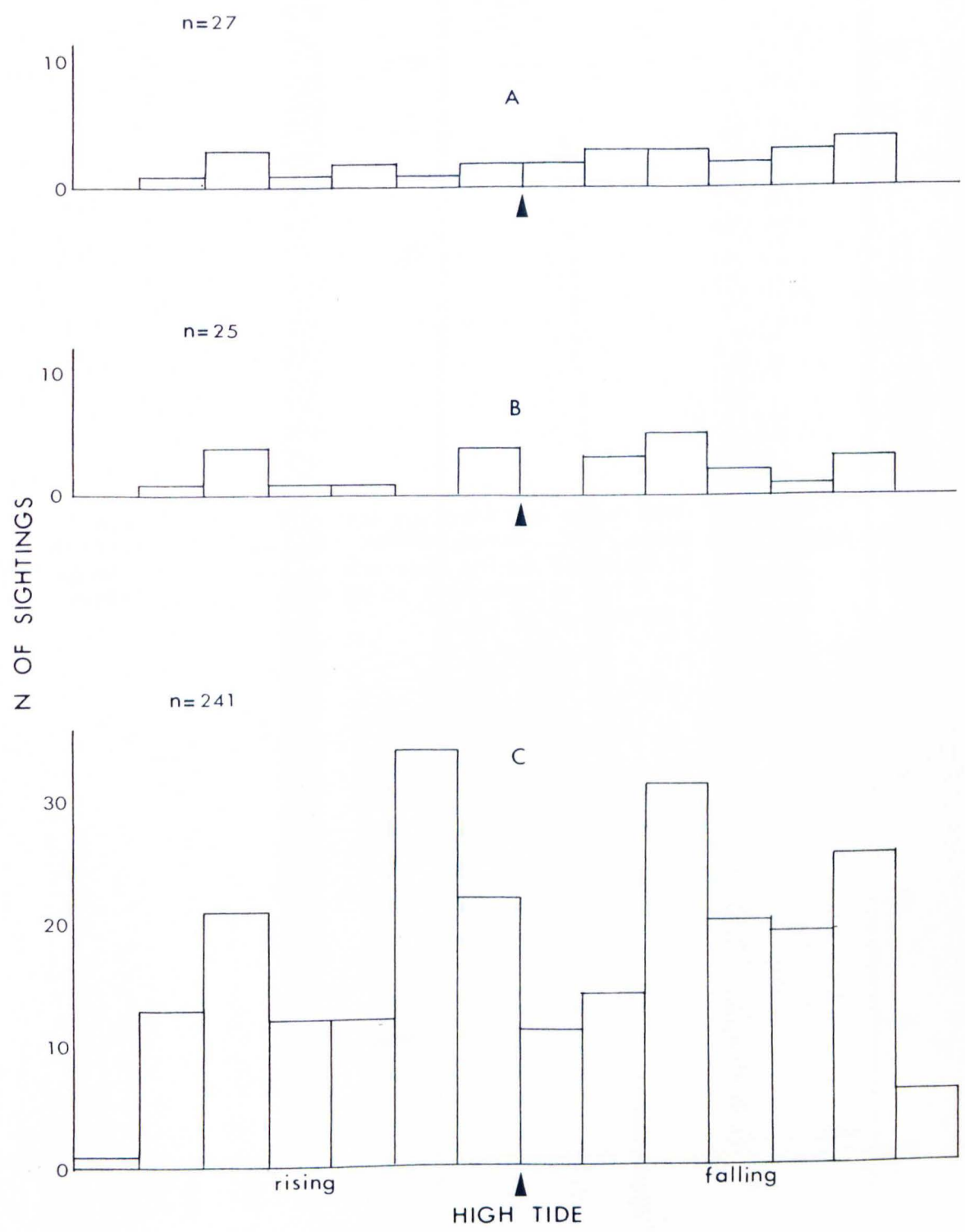


FIGURE 10. Ship noise interference during fin whale sound production. Sonagrams are from prior to approach of ship and during approach of ship. Note change in relative intensity of 60 Hz noise. Analyzing bandwidth = 19 Hz.

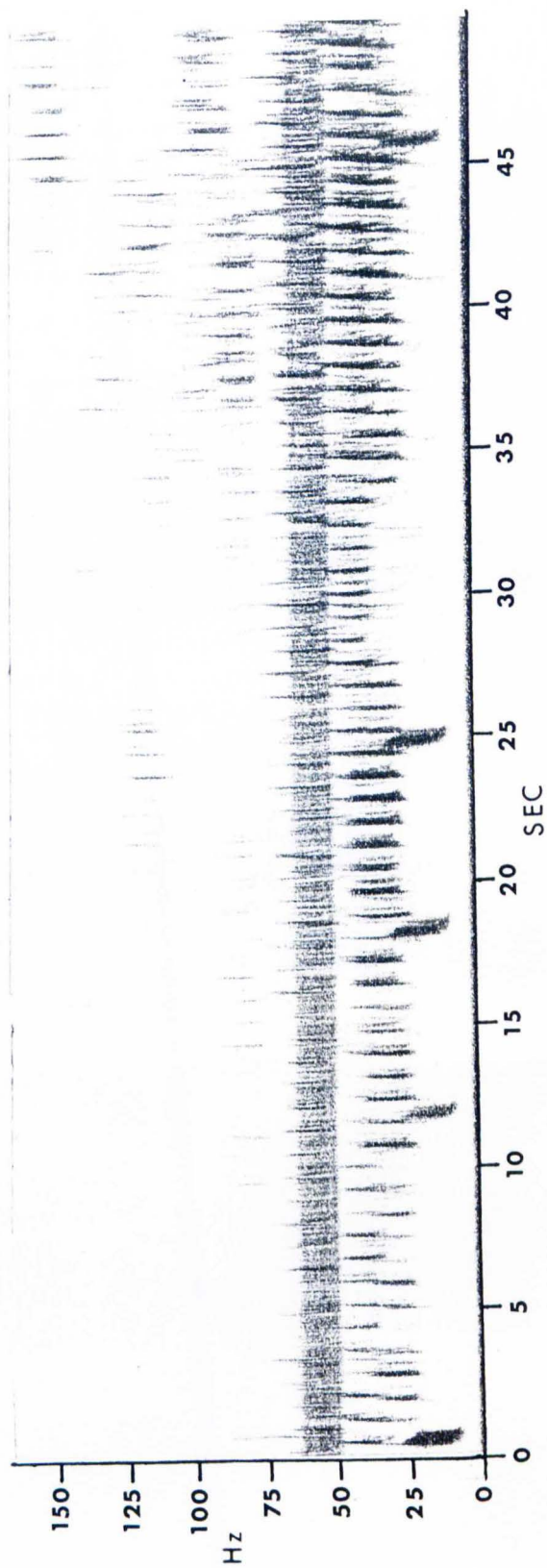
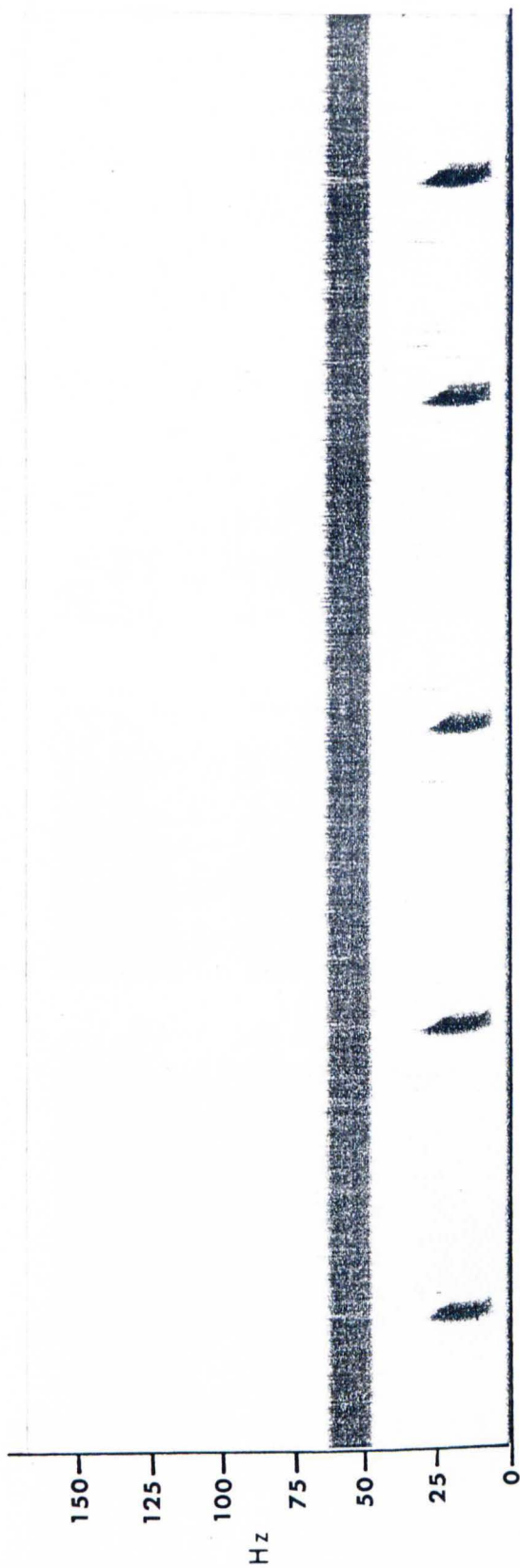
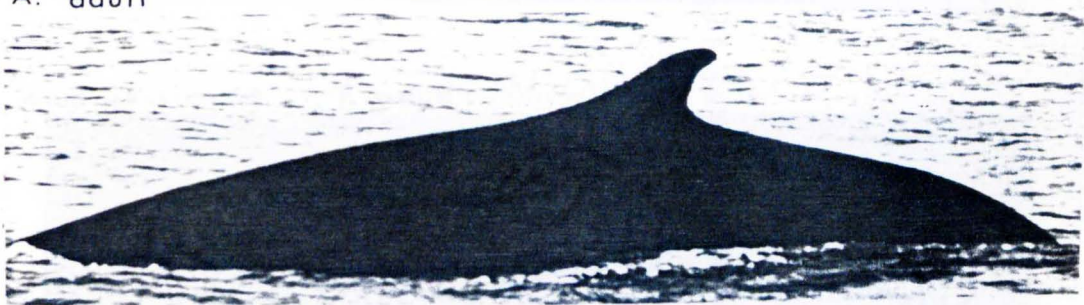


FIGURE 11. Fin whales photographed during recording session. Each individual in a sighting has been given a new letter. Session numbers given include subsessions. Intra- and intersession comparisons may be made using the session numbers also found in Figs. 36 and 37.

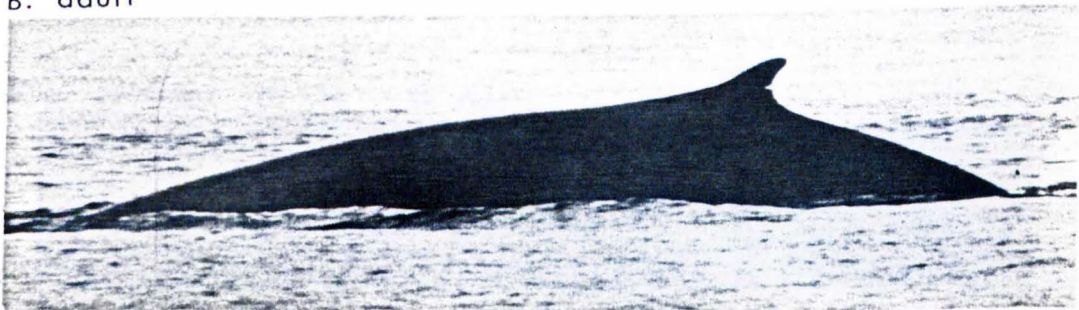
- A. No resighting with recording.
- B. No resighting with recording.
- C. No resighting with recording.
- D. Resighting, I, L, N, P.
Possibly F, J, O.
- E. Size not seen well due to fog.
Not noted as a calf, possibly H.
- F. Angle of back too arched.
Possibly D.
- G. Has very small notch near base of dorsal fin.
Resighting K, possibly W.
- H. Large calf associated with D (=I), therefore
Possibly E.
- I. Resighting D, L, N, P.
Possibly O.
- J. Possibly D (from similar photo taken during D
sighting).
- K. Resighting G.
Possibly W.
- L. Resighting D, N, P.
- M. No resighting with recording.
- N. Resighting D, I, L, P.
Do not have photo of calf with this whale, or of other
adult present during sighting, presence of calf
strengthens identification.
- O. Poor photo, only one available. Poor photo of
I was sorted with this photo: possibly I.
- P. Resighting D, I, L, N. Not with a calf.
- Q. No resighting with recording.
- R. Difficult to see; more valuable for whom it is not.
Not A, B, C, G, K, M.
- S. Difficult to see; more valuable for whom it is not.
Size difference between adult and calf too great
to be D-E or H-I. Definitely not A-C.
- T. See above.
- U. Tip of dorsal fin pointed considered to be new whale.
- V. Possibly L. No photo.
- W. Resighting G.

31 July sessions 1-5

A. adult



B. adult



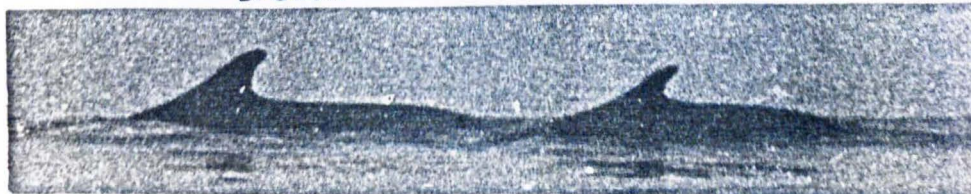
C. calf



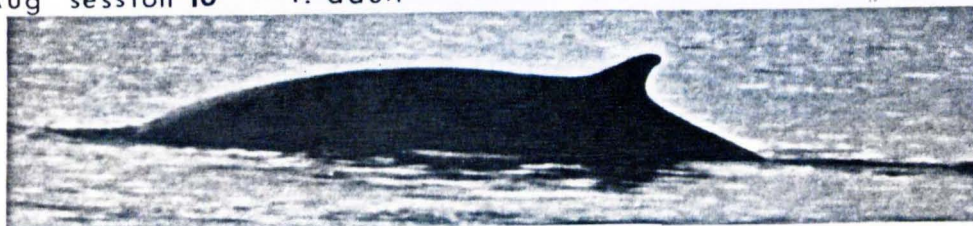
1 Aug sessions 6-7 (foggy)

D. adult

E. adult ?



12 Aug session 10 F. adult



14 Aug sessions 13-14 G. adult



H. calf

sessions 14-15

I. adult



I. adult



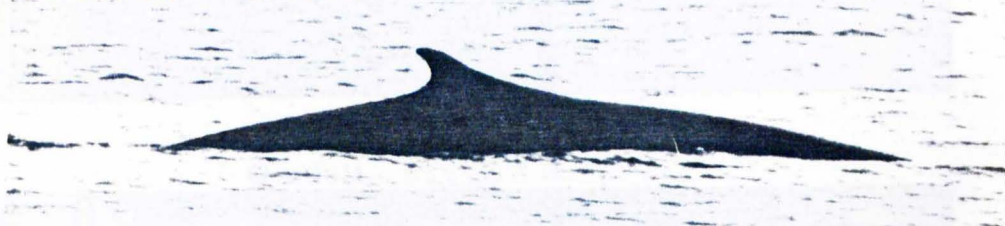
15 Aug session 16 J. adult



K. adult



16 Aug no sounds L. adult



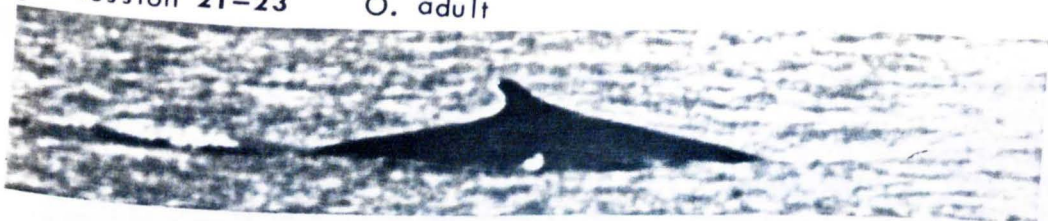
no sounds M. adult



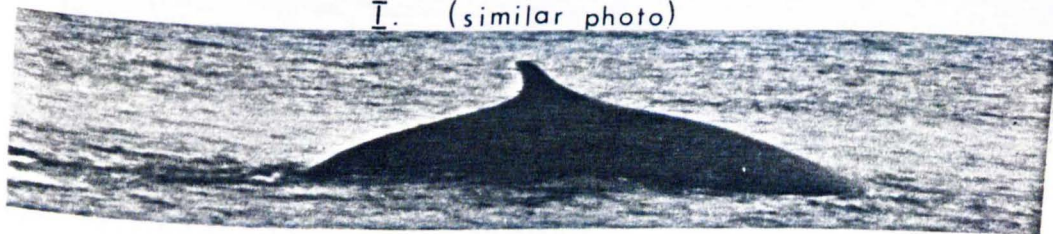
16 Aug sessions 17-20 N. adult of A-C pair; no calf photo



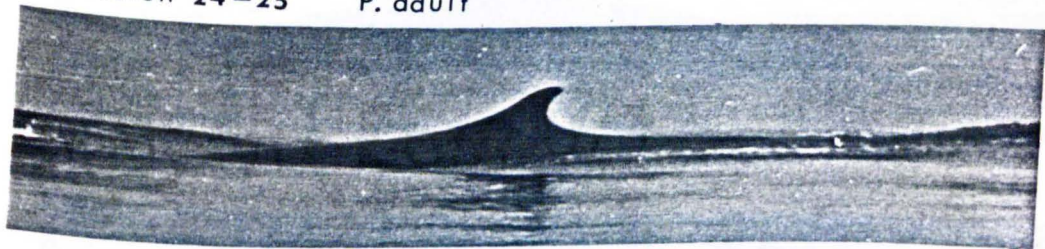
16 Aug session 21-23 O. adult



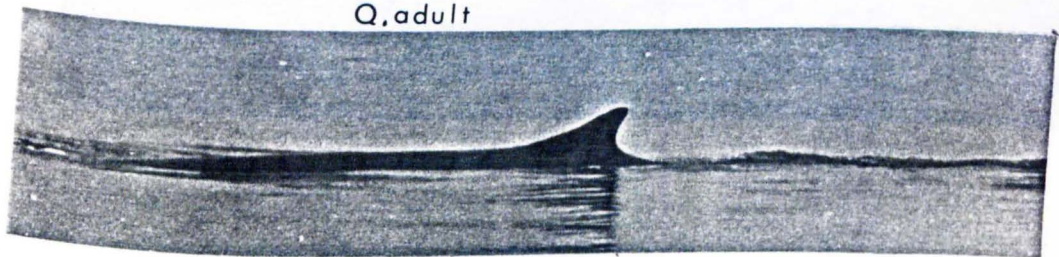
I. (similar photo)



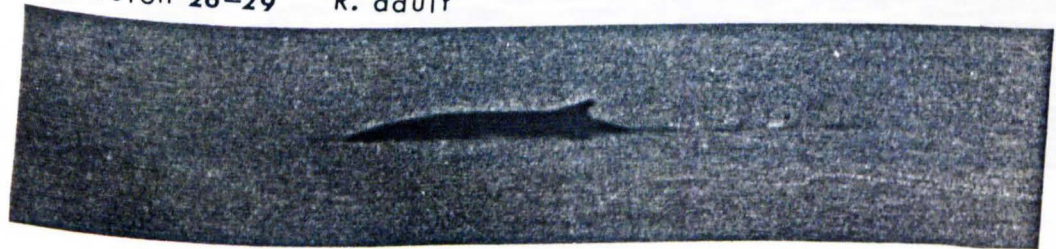
18 Aug session 24-25 P. adult



Q. adult



19 Aug session 26-29 R. adult



1 Sept session 31-32 S. calf

T. adult



1 Sept session 33-35

U. adult



V. adult



15 Sept session 39-44

W. adult



FIGURE 12. Intensity measurements for consecutive calls of a fin whale moving past the hydrophone. The arrow indicates approximate call given nearest to hydrophone. Whale was 400 m from shore while in transit.

- A. Whale approached hydrophone from downstream between call 1 and 50.
- B. Whale headed away from hydrophone (upstream) from 50-120. Intensity is dB re 20 μ Pa. Total time is 24 min.

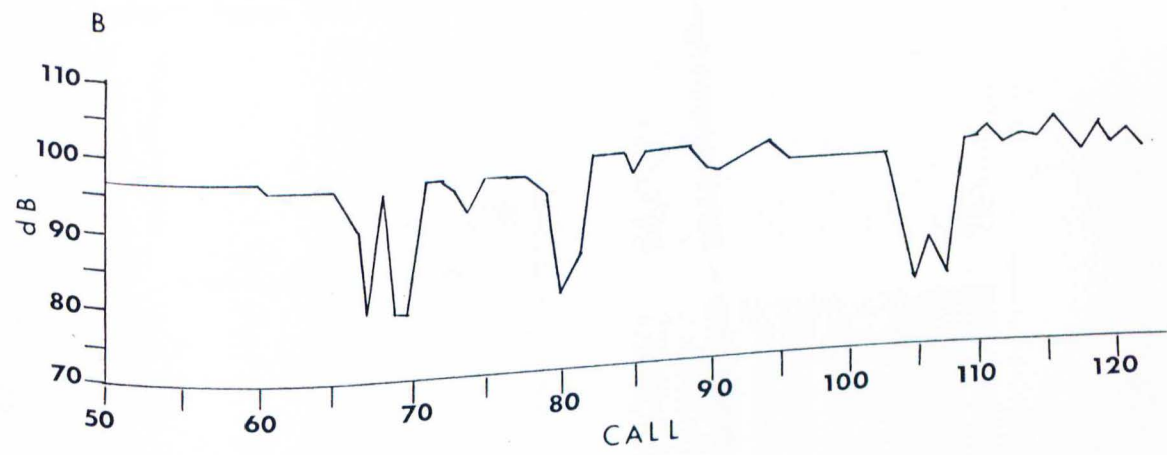
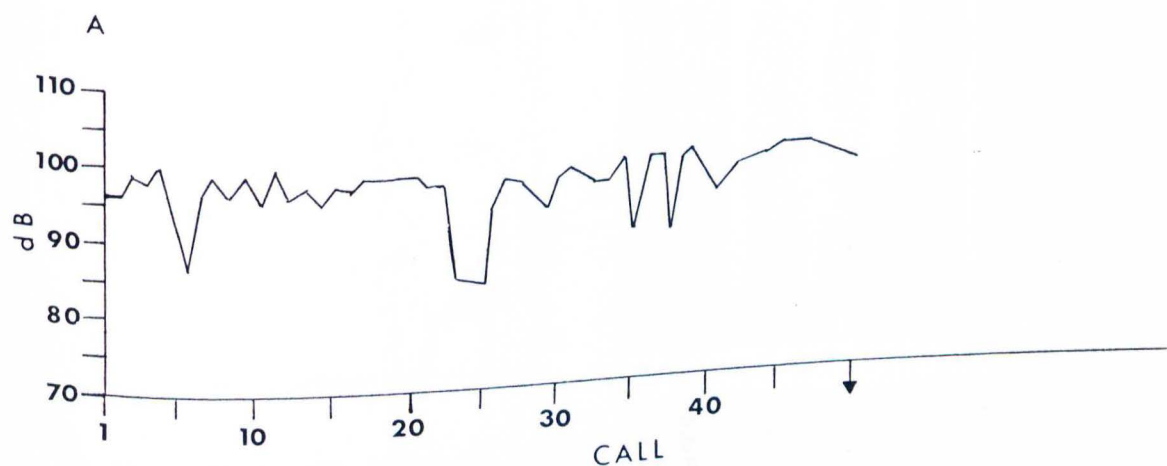
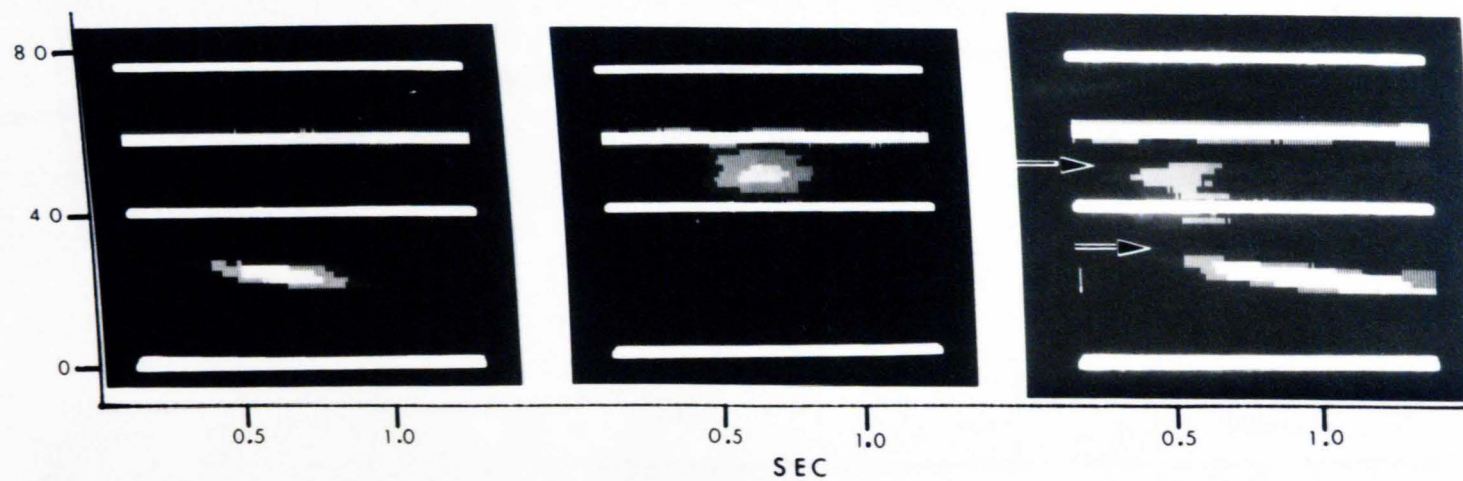
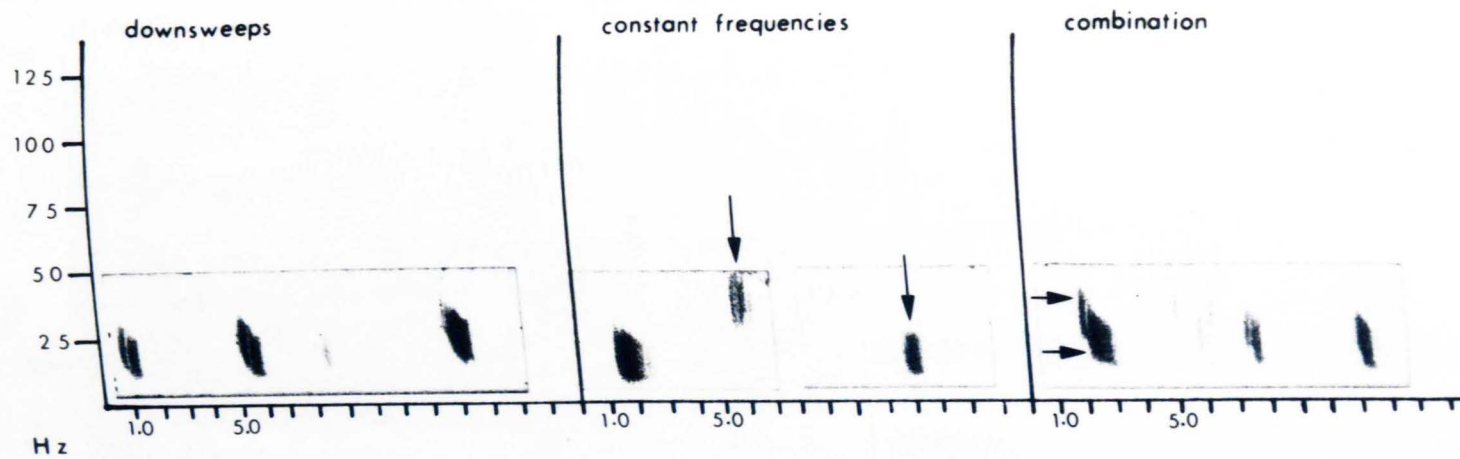


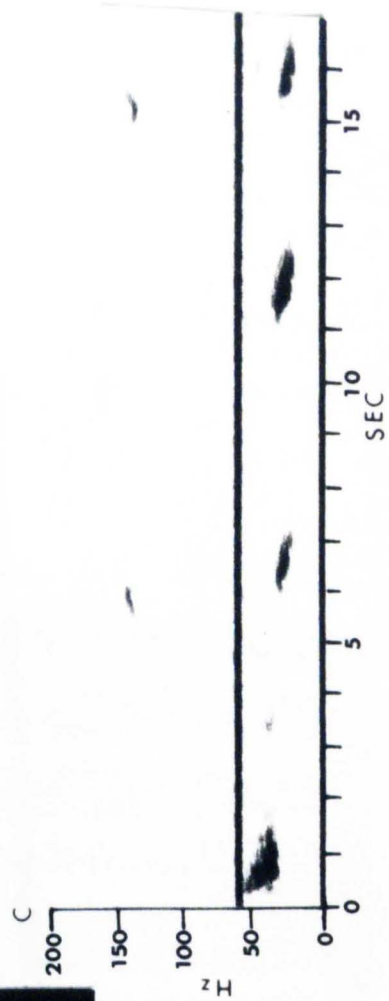
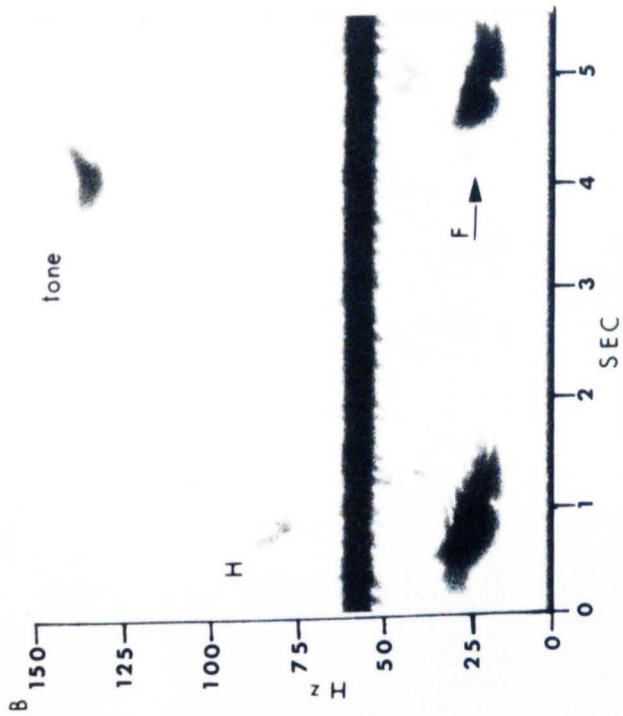
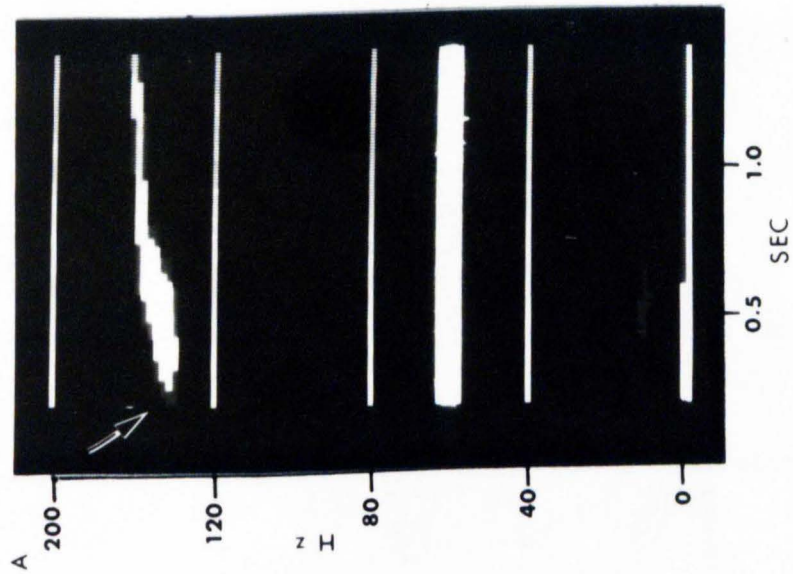
FIGURE 13. Sonagraph and real time analyzer representations of downsweeps, constant frequencies calls and the combination call. Arrows indicate high and low constant frequency calls and the two components of the combination call.



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FIGURE 14. Sonagraph and real time analyzer representations of the tone.

- A. A rising tone
- B. Scale magnification of a tone and the downsweeps which precede and follow. H, harmonic from intense downsweep; F, possible fundamental for tone.
- C. Series of downsweeps with two tones.
Rising tone is the one illustrated in B.
Sonagram analyzing bandwidth = 2.8 Hz.



81a

FIGURE 15. Representations of the waver, upsweep, split call and double call.

- A. and B. No real time analyzer (RTA) screen photographs were useable. Analyzing bandwidth = 2.8 Hz.
- C. Lower intensity of upper portion of split call was only visible on RTA screen photographs. Initial frequency (FI) is lower than the highest frequency value (FH). The lowest frequency (FL) is the final frequency. The second photograph is an example of a split call that is very similar to a downsweep.
- D. Sonagram of double calls. Double calls were not photographed since the entire call sequence was not visible on the screen. Analyzing bandwidth = 19 Hz.

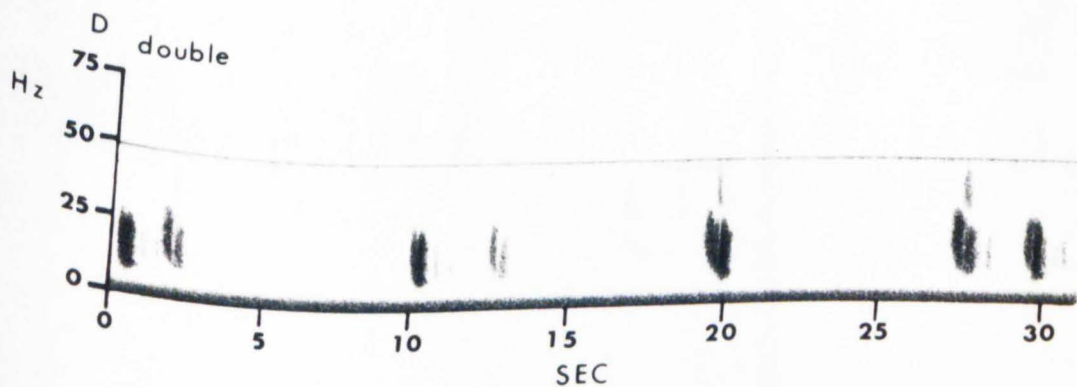
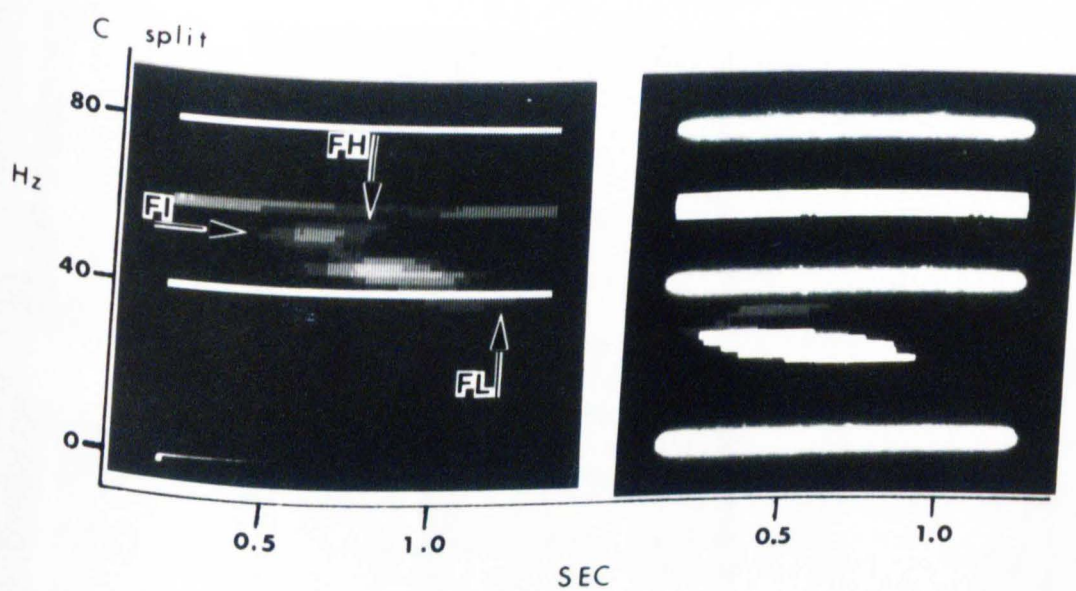
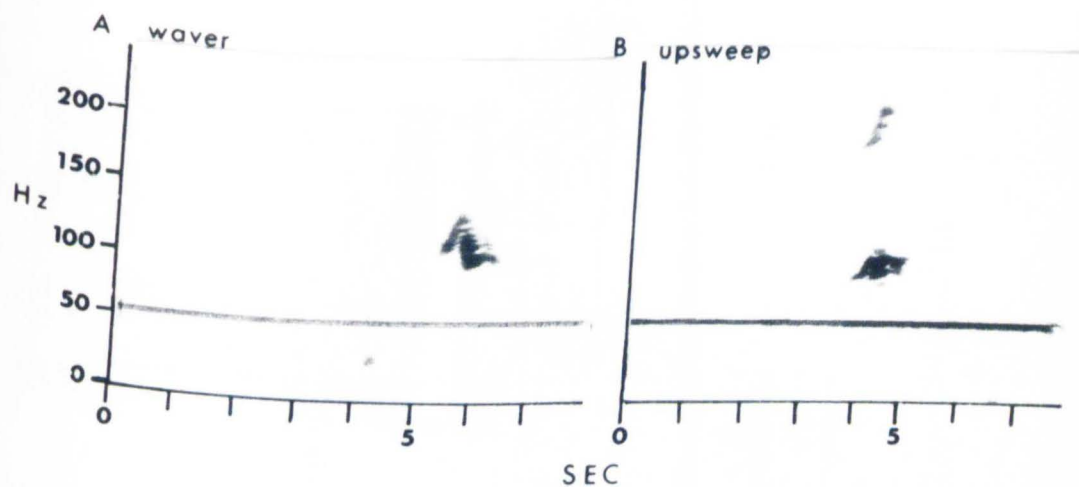
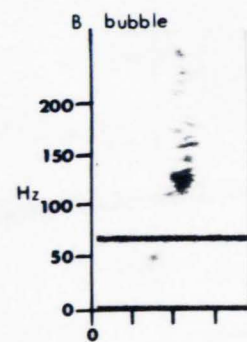
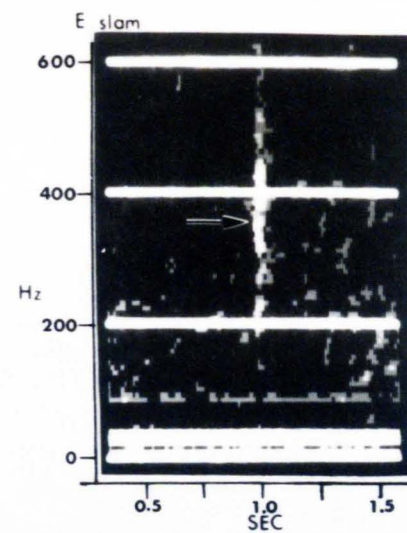
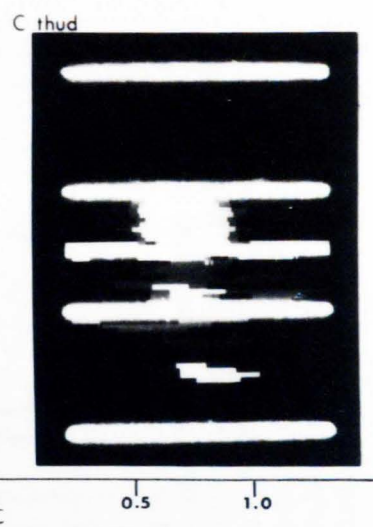
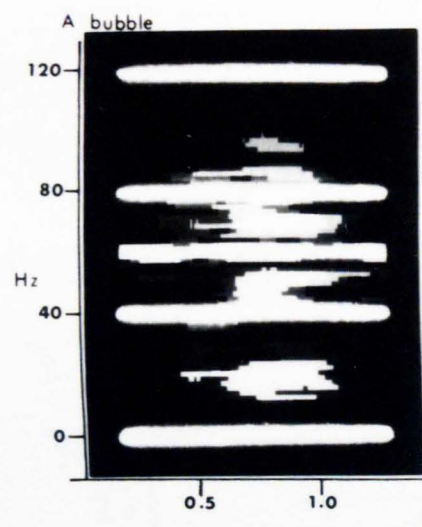
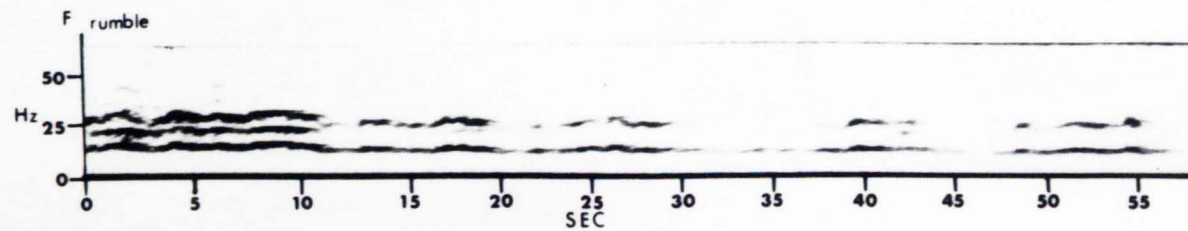
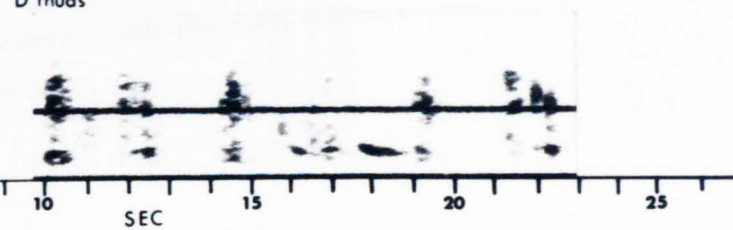


FIGURE 16. Representations of the bubble sound, thud, slam, and rumble.

- A and B. Two different bubble sounds. Sonagram analyzing bandwidth = 2.8 Hz.
- C. A single thud.
- D. A series of thuds; note trio of decreasing FH values at 22 sec. A downsweep appears at 18 sec. Analyzing bandwidth = 2.8 Hz.
- E. A high frequency slam. The brief duration and different wide-band nature of the slam make it difficult to photograph or see on a sonagram. My measurements were restricted to below 200 Hz.
- F. Rumbles exhibiting frequency and amplitude modulation. The presence of harmonics appear to be related to higher intensities. Analyzing bandwidth = 2.8 Hz.



D thuds



032

FIGURE 17. Comparison of FH (frequency high) and FL (frequency low) for all structures described. 1, downsweep; 2, constant frequencies; 3, combination; 4, tone; 5, waver; 6, upsweep; 7, split call; 8, double calls; 9, bubble sound; 10, thud/slam (components of the slam were not measured above 200 Hz); 11, rumble with range only.

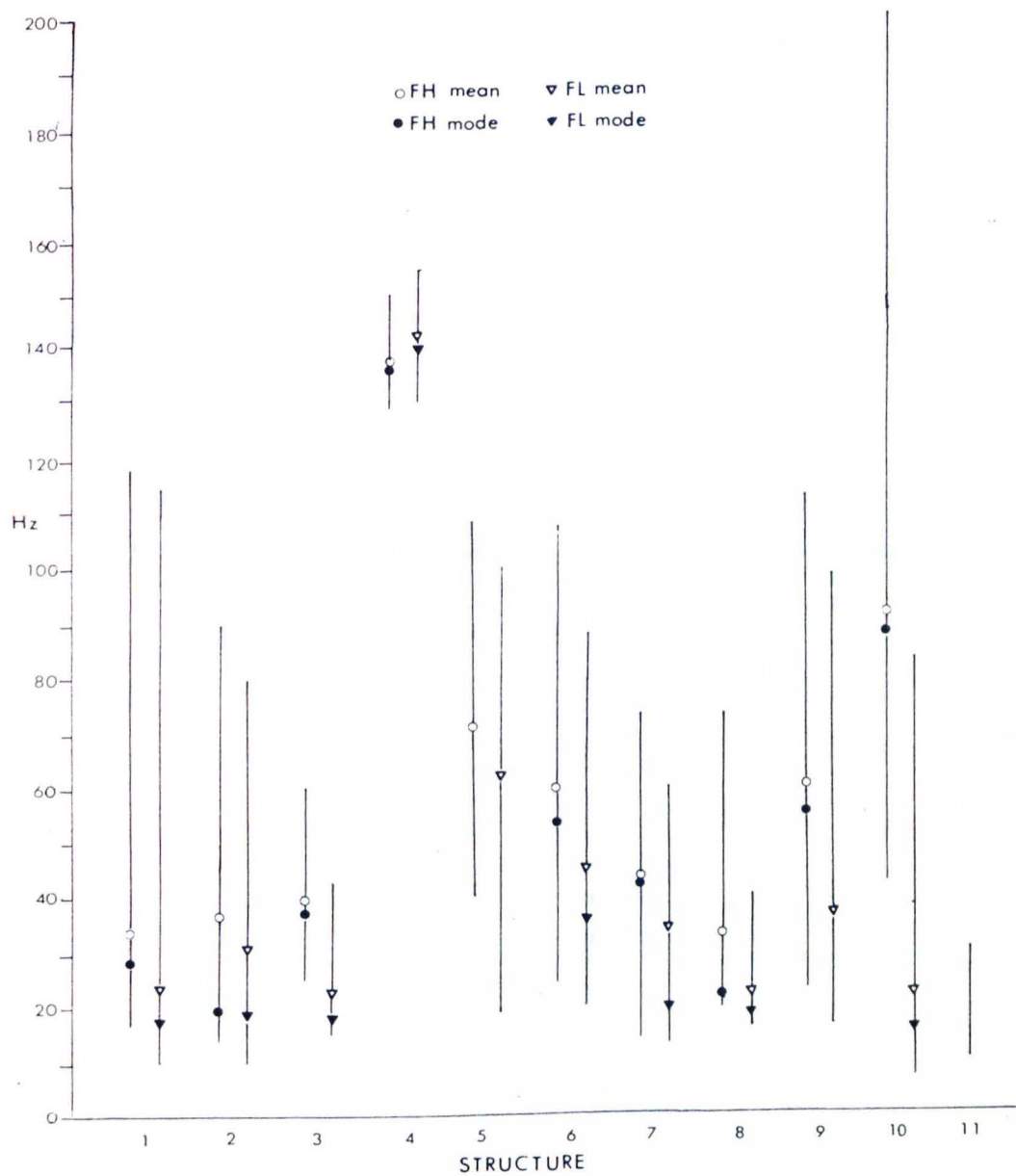


FIGURE 18. Ranges for total duration (TD) and frequency difference (FD) for all structures measured. $FD = FH - FL$. Structure numbers correspond to previous figure.

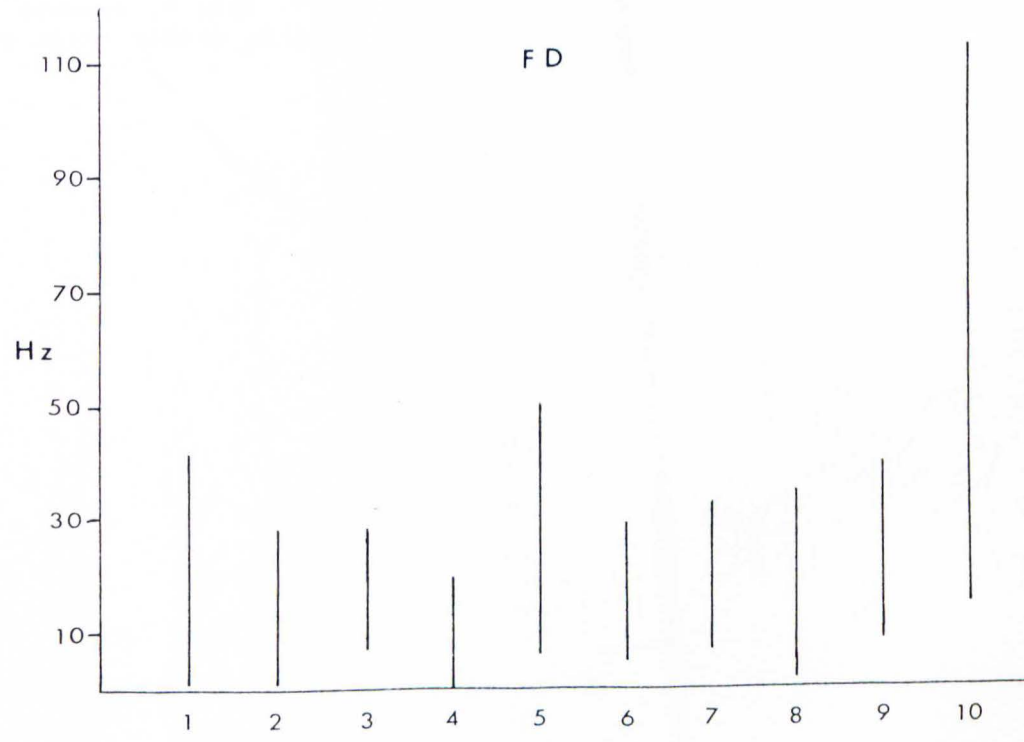
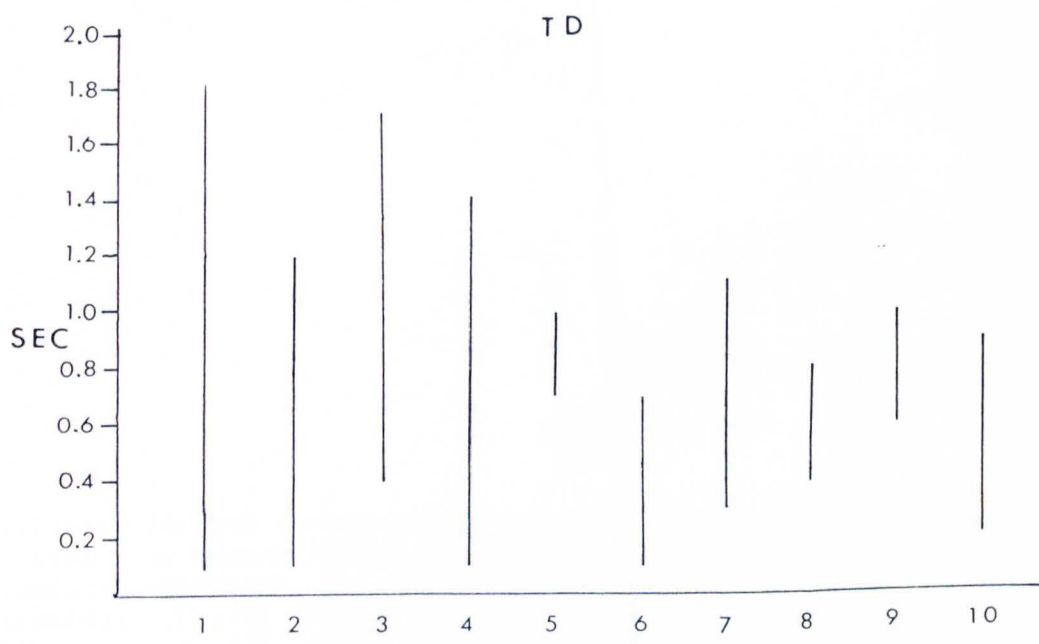


FIGURE 19. Relative frequency of occurrence for all quantified structures. Wavers and bubble sounds were less than 1% and do not appear. 1, downsweep (n=1244, 82%); 2, constant frequencies (n=108, 7%); 3, combination call (n=16, 1%); 4, tone (n=45, 3%); 6, upsweep (n=13, 1%); 7, split call (n=19, 1%); 8, double calls (n=9, 1%); 10, thud/slam (n=56, 4%).

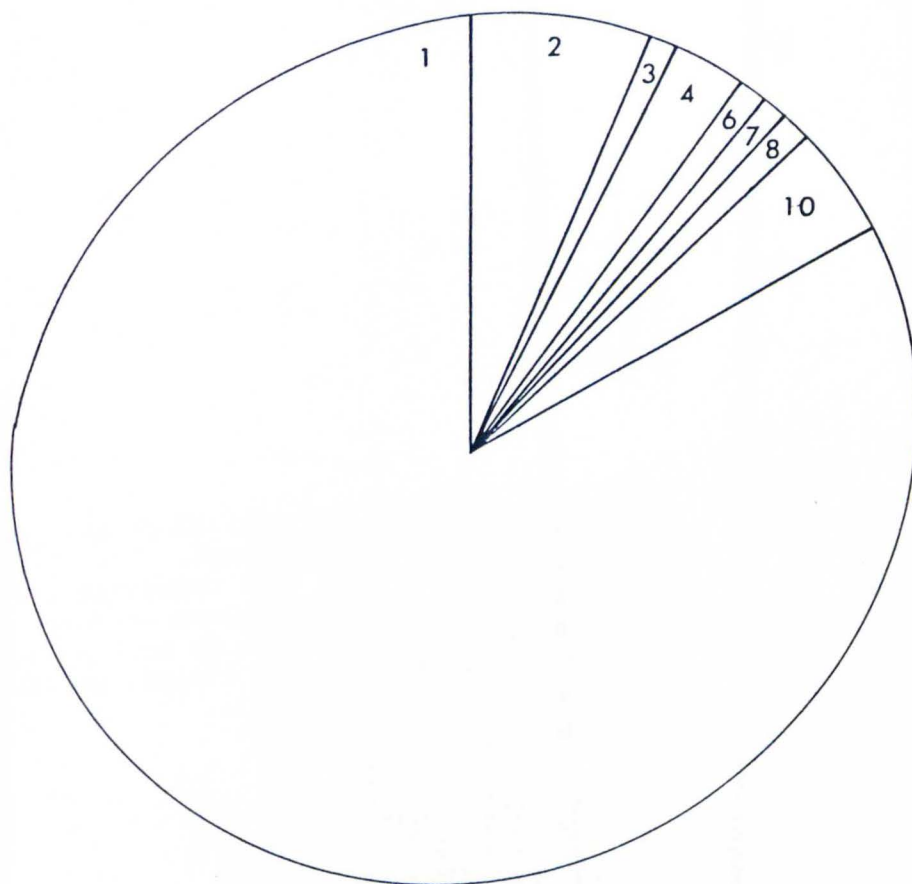


FIGURE 20. Final frequency (FF) and initial frequency (FI) relationship for all downsweeps. Each star represents one point at that coordinate, 2-8 indicate actual number of points at that coordinate; 9 indicates nine or more points at that coordinate. $r=.93$; $r^2=.86$; $n=1180$.

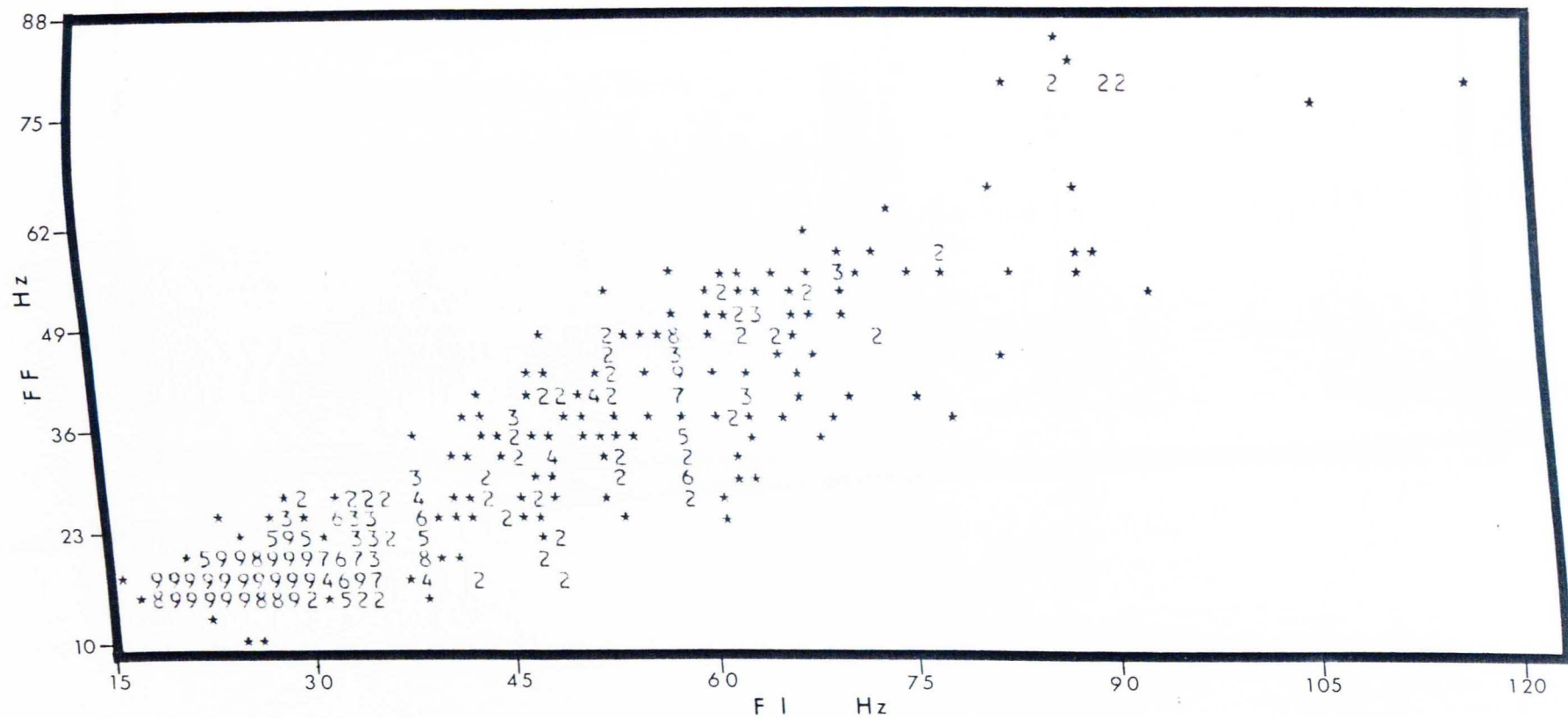


FIGURE 21. Frequency difference (FD) and initial frequency (FI) relationship for all downsweeps. A concentration of values occurs below FI=45 Hz. $r=.71$; $r^2=.51$; $n=1173$.

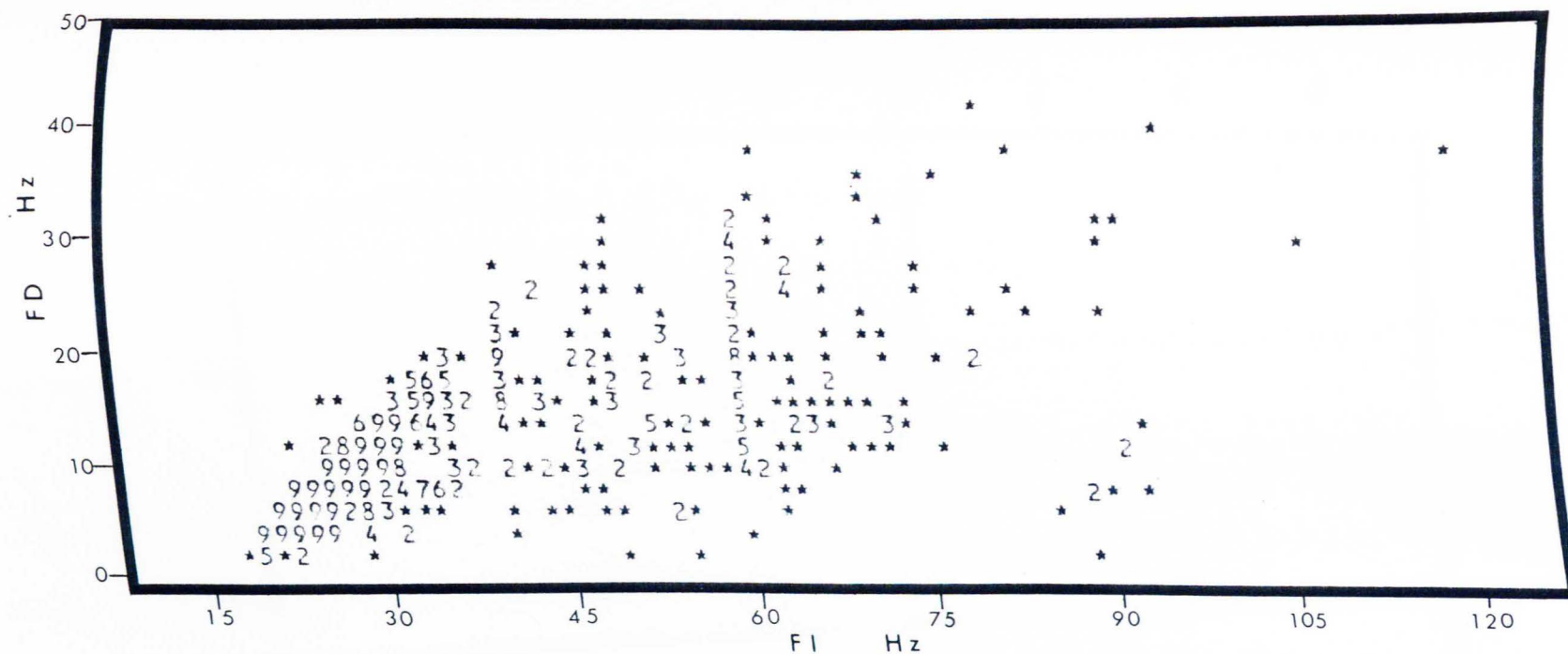


FIGURE 22. Final frequency (FF) and initial frequency (FI) for downsweeps with $FI > 44$ Hz. $r=.81$; $r^2=.66$; $n=209$.

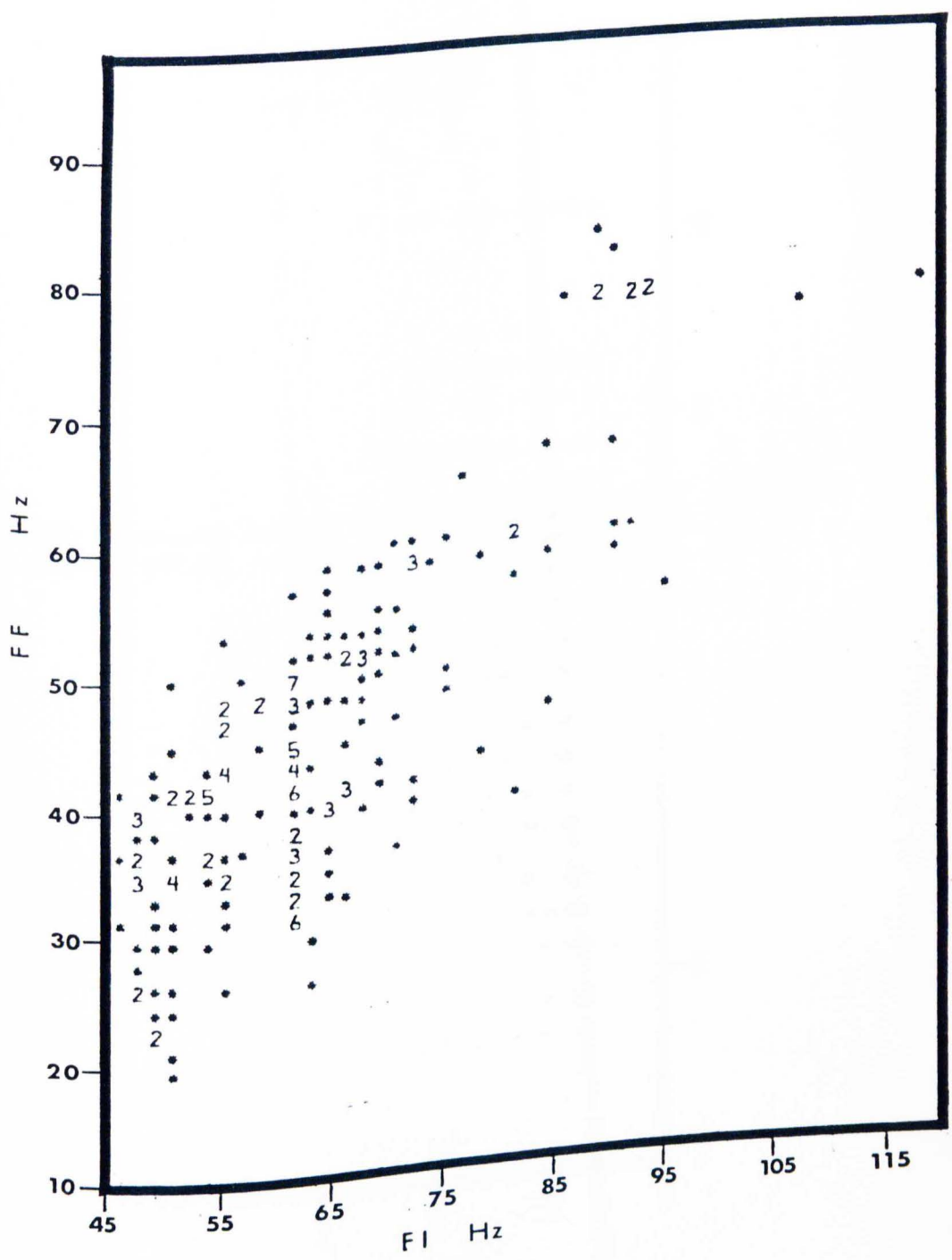
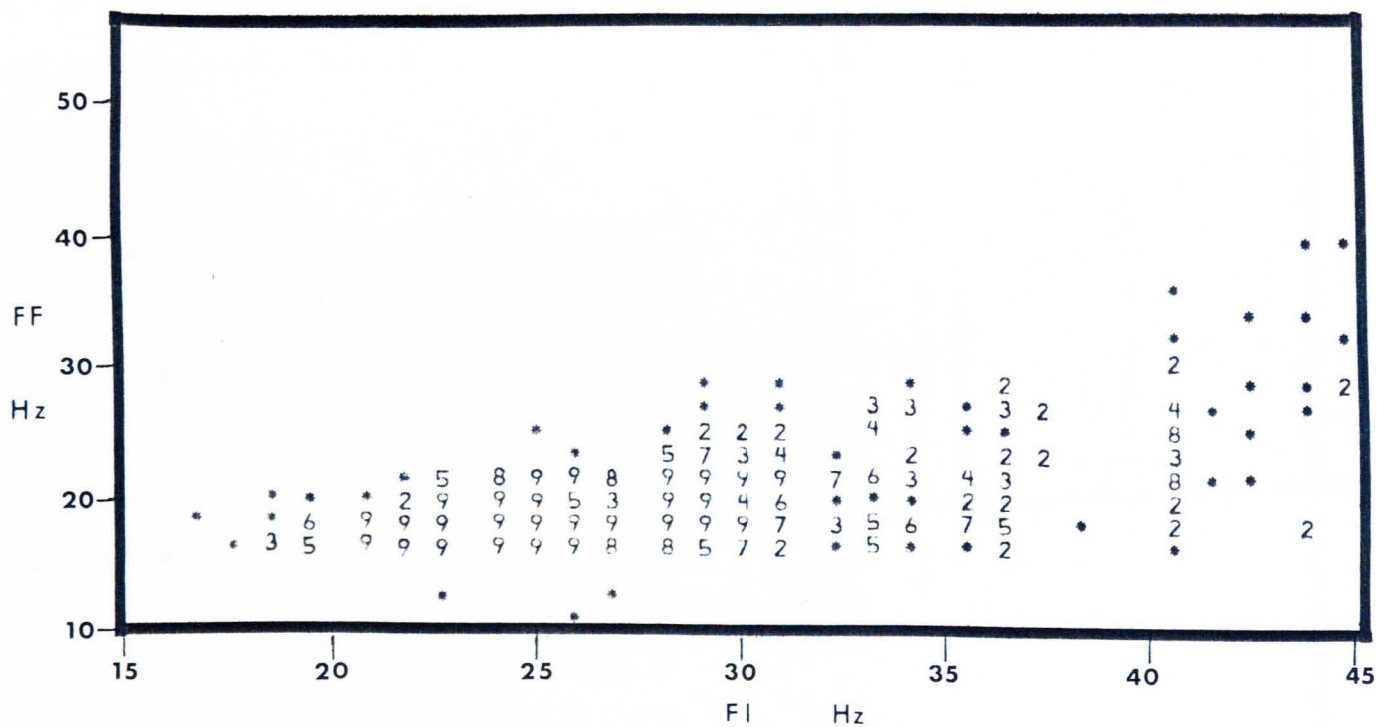


FIGURE 23. Final frequency (FF) and initial frequency (FI)
for downsweeps with $FI \leq 44$ Hz. $r=.59$; $r^2=.36$;
 $n=966$.



9002

FIGURE 24. Initial frequency (FI) and frequency difference (FD) for downsweeps with FI $\leq$ 44 Hz. $r=.79$; $r^2=.64$; $n=964$.

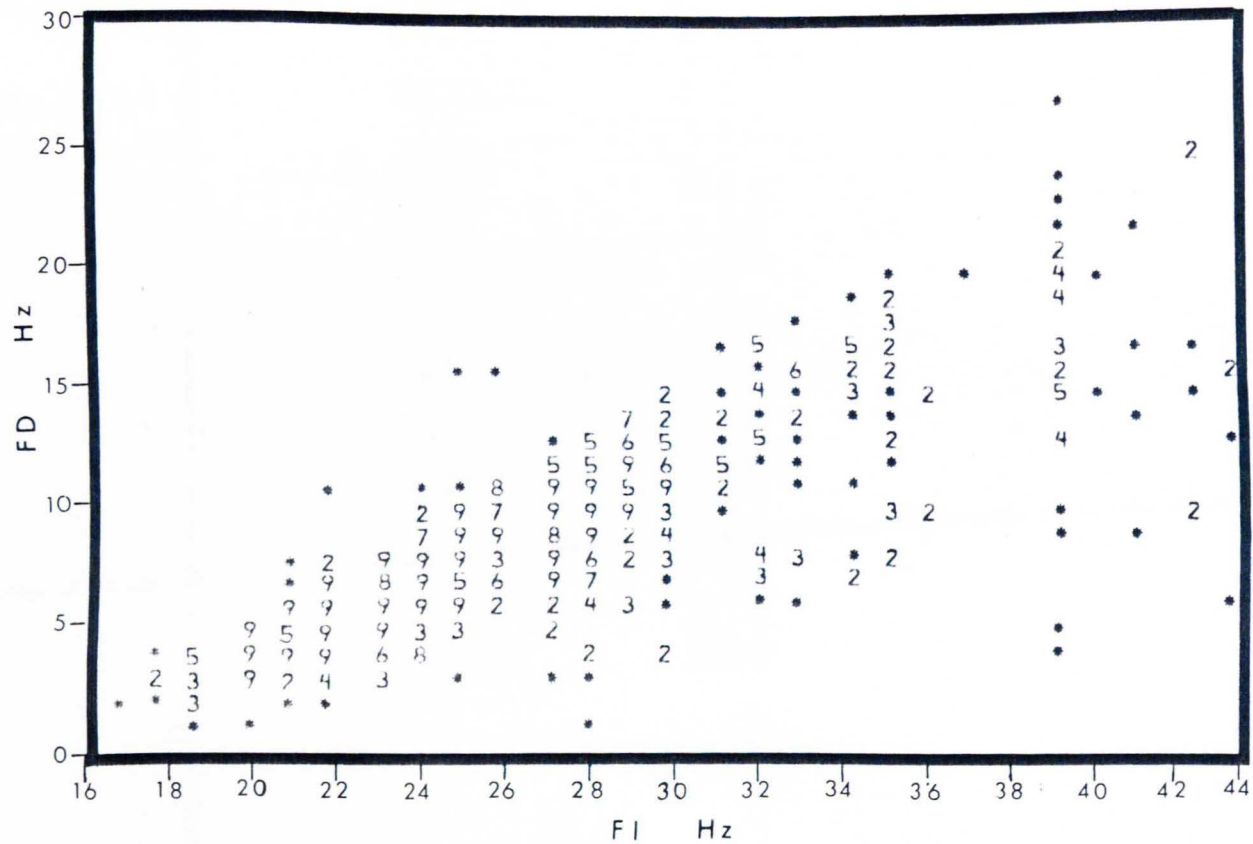


FIGURE 25. Final frequency (FF) and frequency difference (FD) for all downsweeps. The concentration of points below 30 Hz corresponds to an FD of 1-20 Hz. $n=1173$.

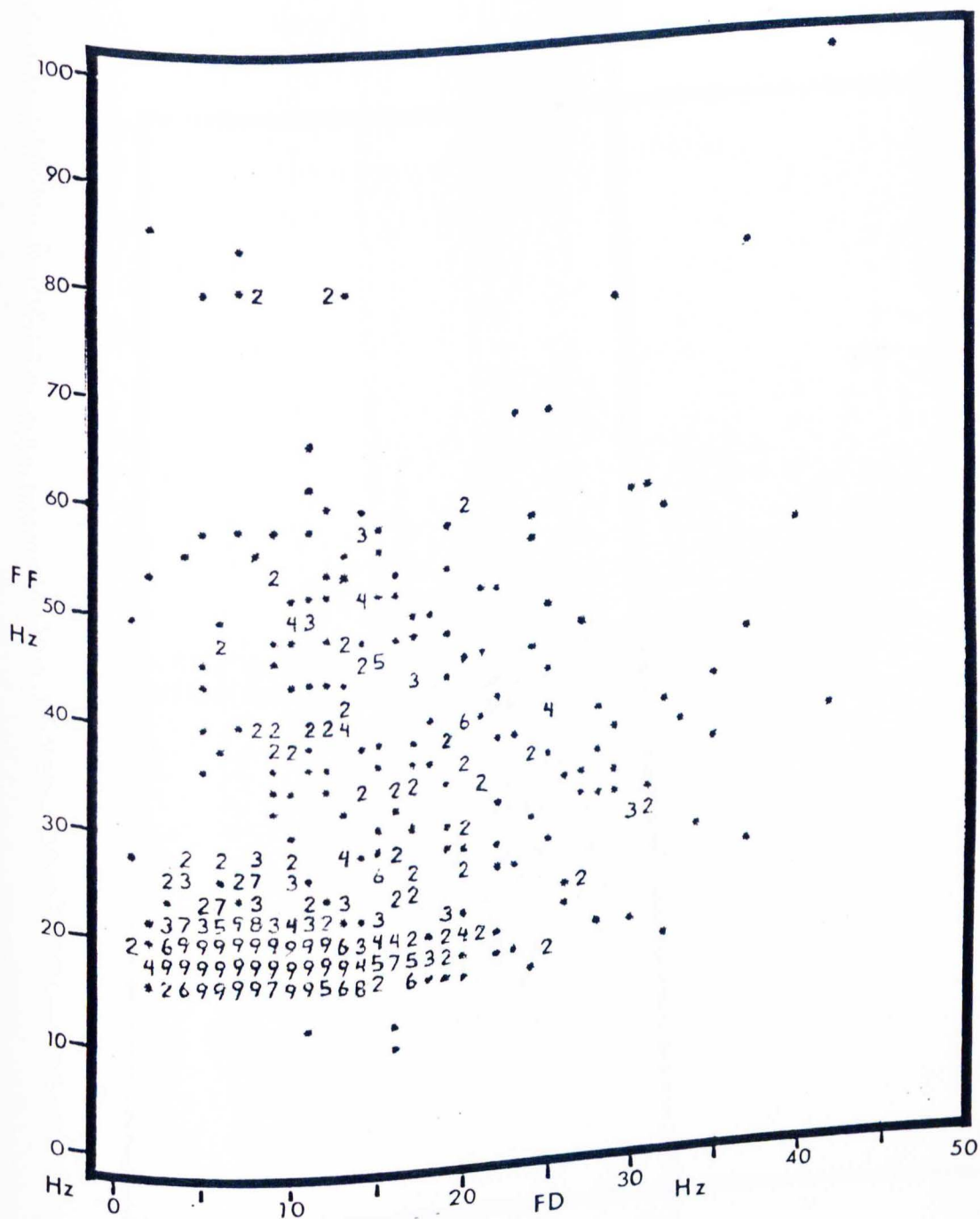


FIGURE 26. Frequency high (FH) and frequency low (FL) relationship for constant frequencies calls.
 $r=.96$; $r^2=.92$; $n=106$.

93a

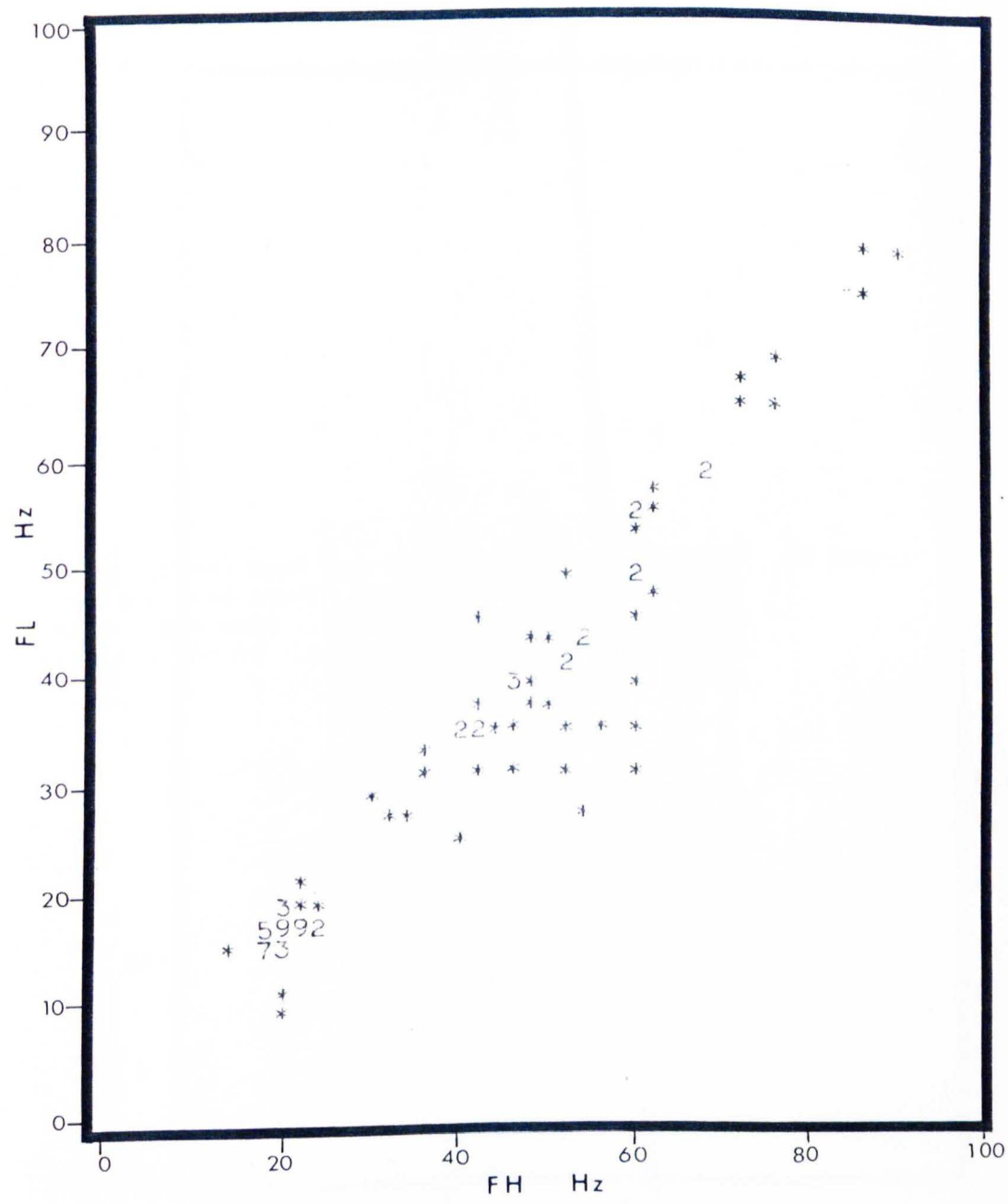


FIGURE 27. Frequency difference (FD) and high frequency (FH) values for thuds and slams. Thuds have smaller FD values and lower FH values. Slam components above 200 Hz were not measured. $r=.68$; $r^2=.47$; $n=54$.

94a

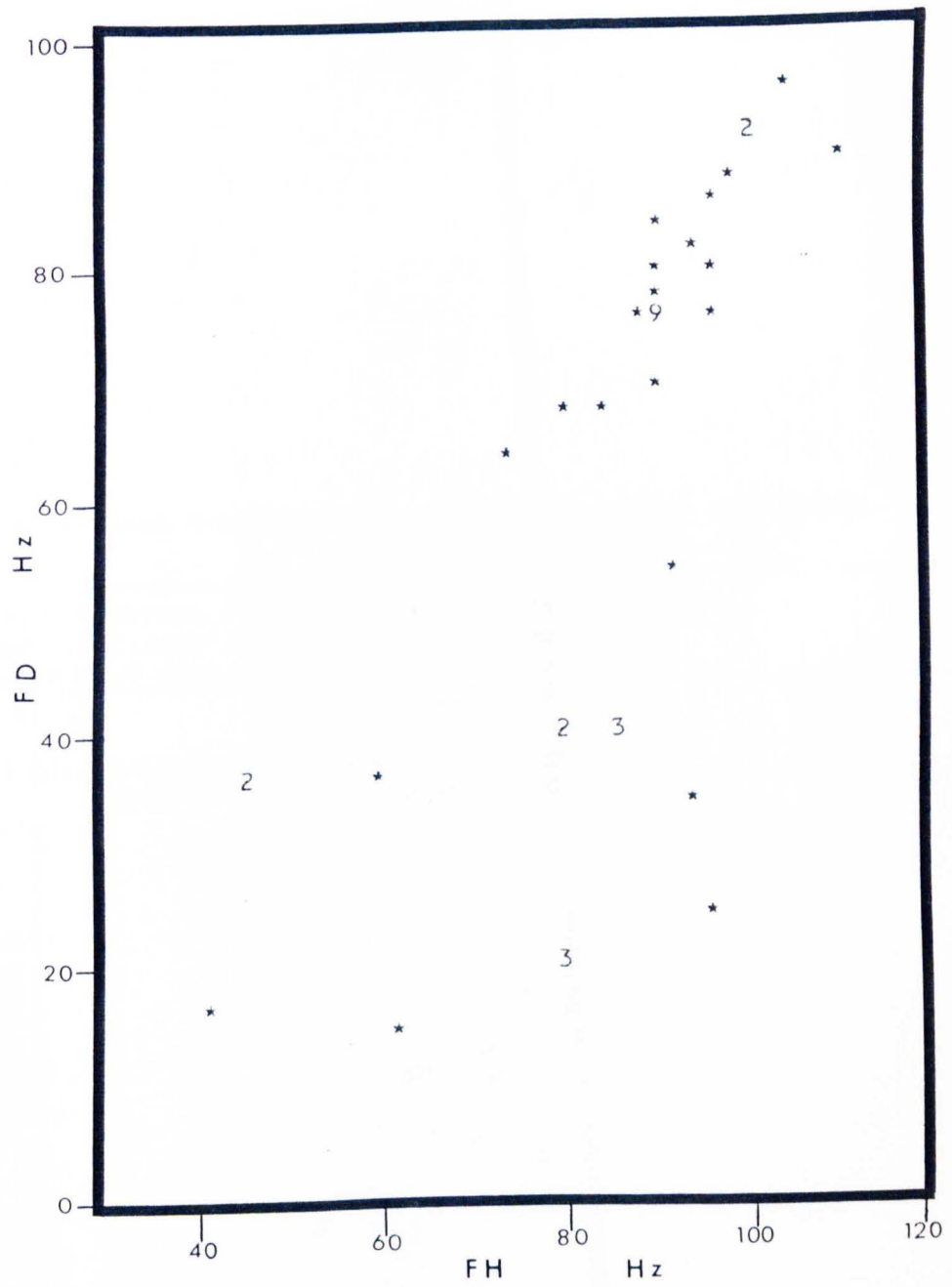


FIGURE 28. Group centroids from discriminant analysis for calls and sounds.

- A. First run: 1, downsweep; 2, constant frequencies; 3, combination; 4, tone; 5, waver; 6, upsweep; 7, split call; 8, double calls; 9, bubble sound; 10, thud/slam.
- B. Second run with downsweeps divided into low (L, $FI \leq 40$) and high (H, $FI > 40$).

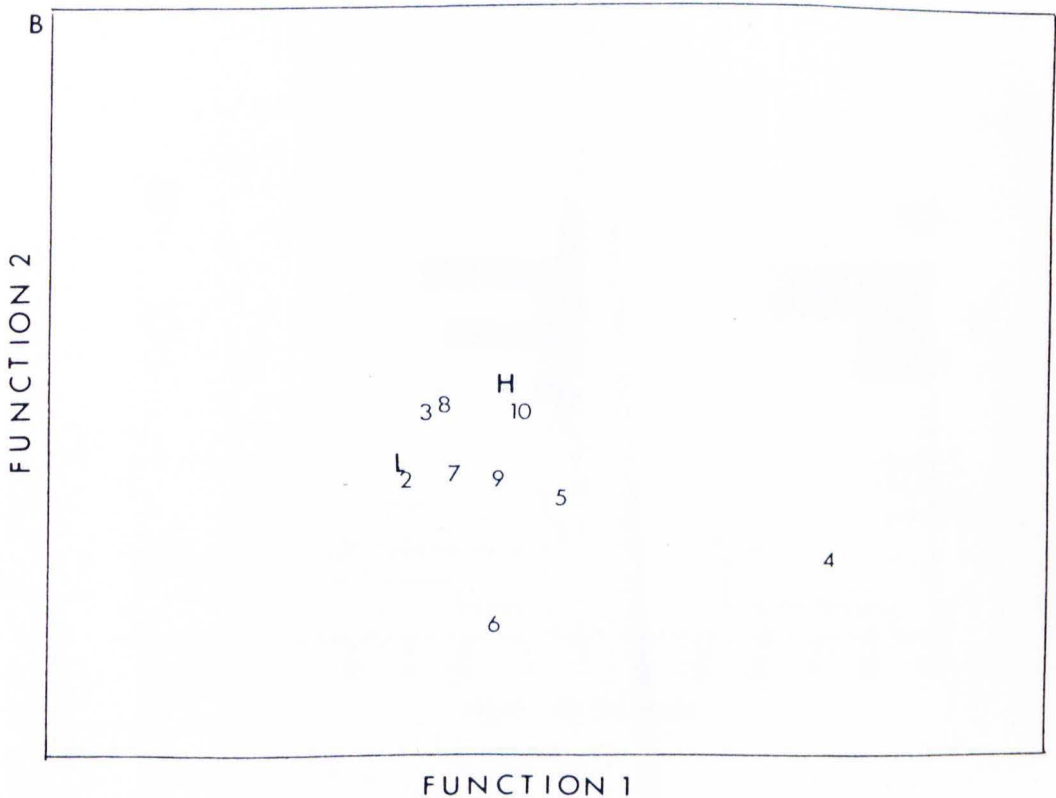
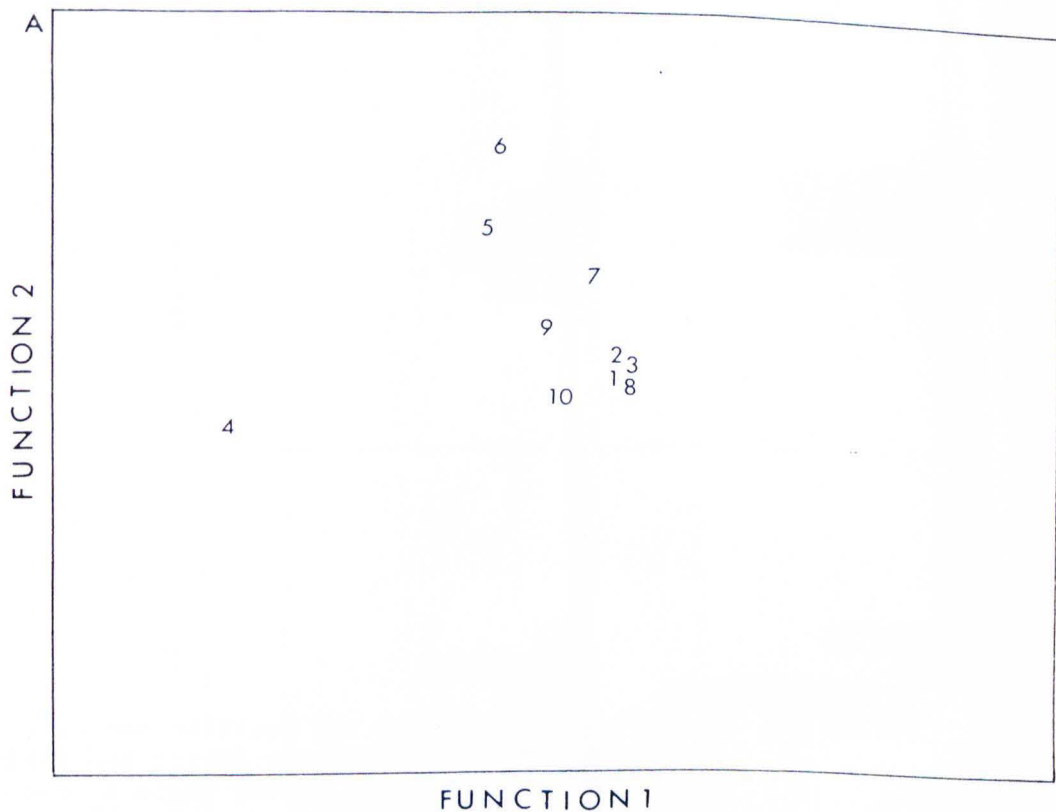


FIGURE 29. Comparison of frequency and duration parameters of downsweeps from single animals during two different sightings. All histogram values begin at zero. FL, lowest frequency; FH, highest; FD, frequency difference.

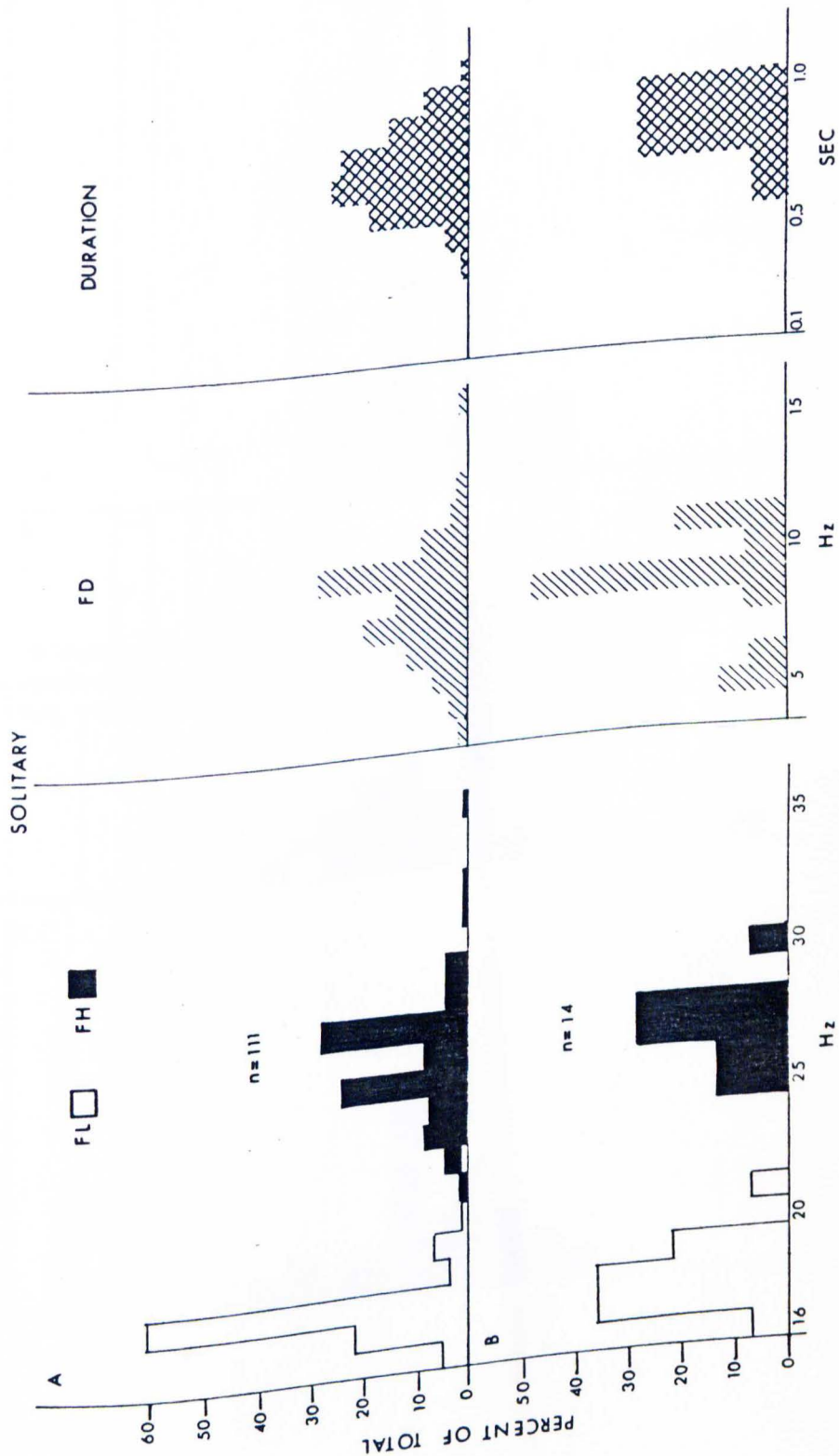


FIGURE 30. Intrasession variability of downsweeps from a single fin whale. A-C consecutive subsessions from Fig. 29A. n =number of calls per subsession.

97a

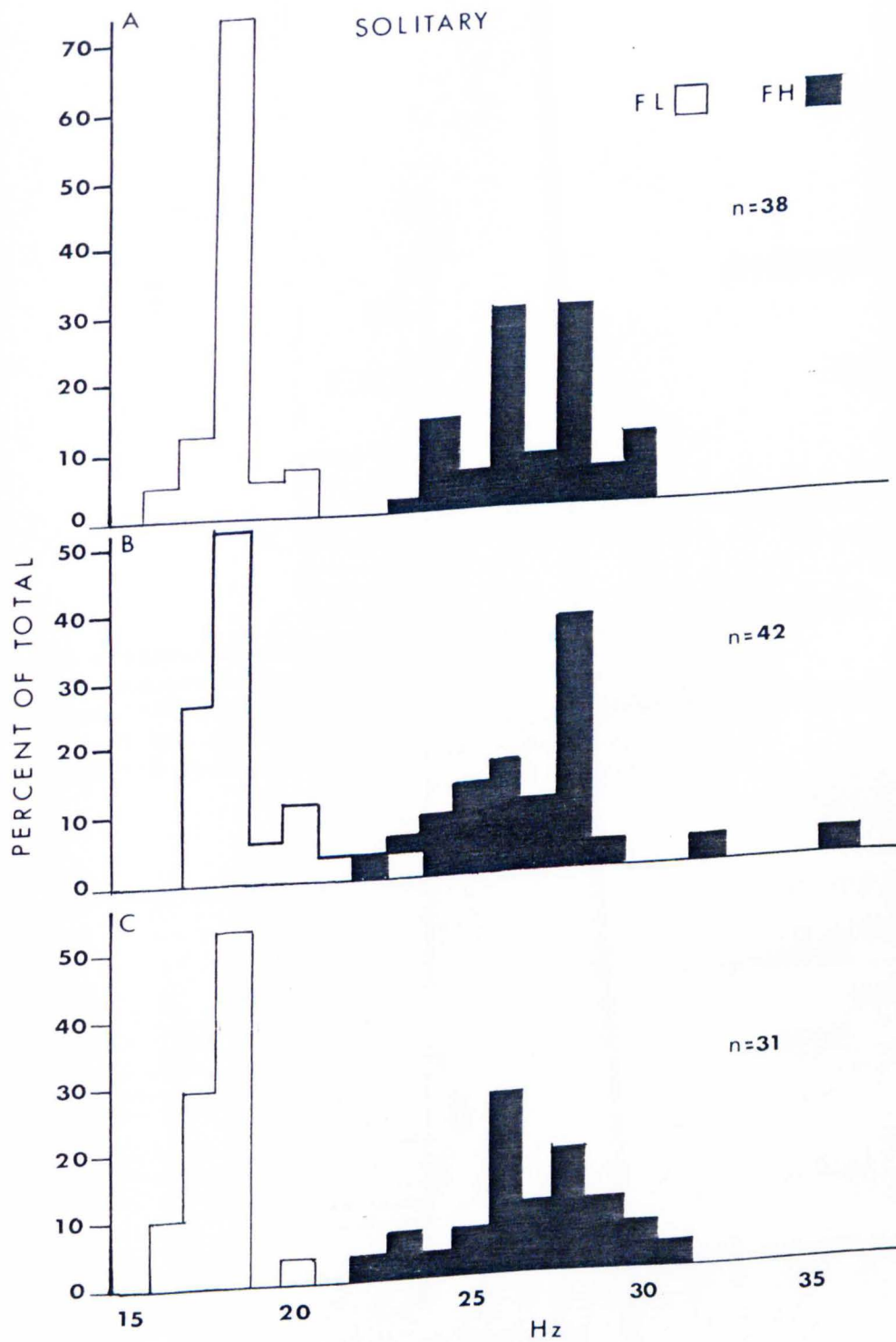
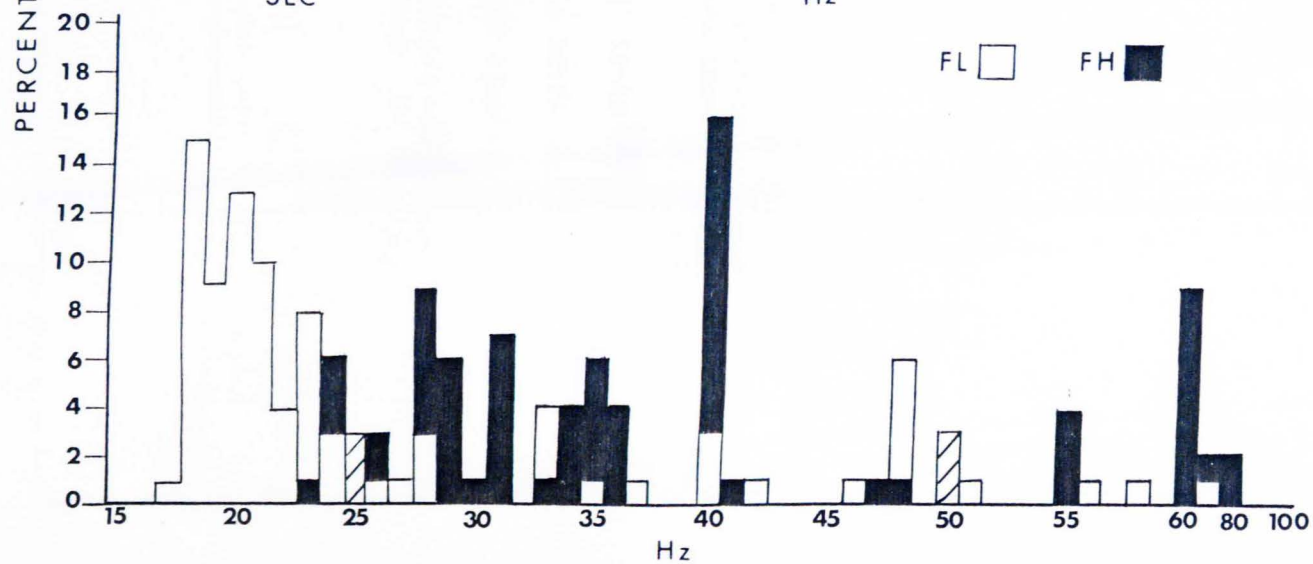
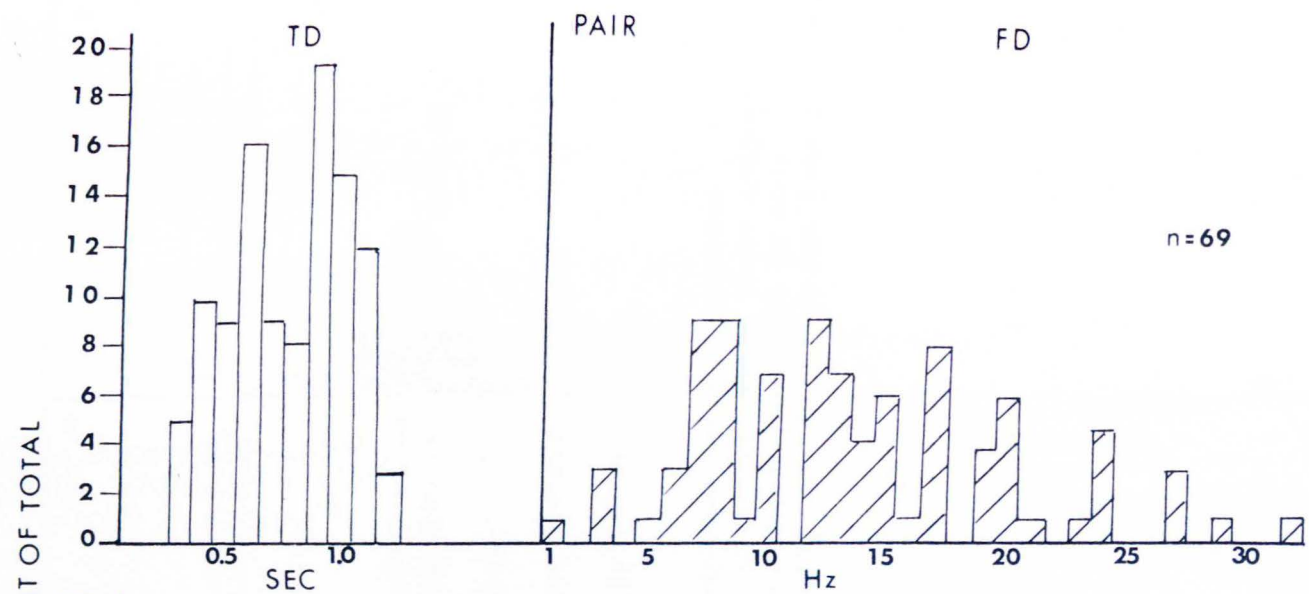


FIGURE 31. Downsweep frequency and duration parameters for a pair of fin whales. FL, lowest frequency; FH, highest frequency; FD, frequency difference; TD, total duration. Cross-hatching for FH, FL histogram indicates equal percentages for both. n=number of calls.



98a

FIGURE 32. Comparison of highest frequency (FH) and lowest frequency (FL) ranges for downsweeps in consecutive sessions involving one to three whales. Cross-hatching indicates equal percentages for FH,FL.

A. Adult 05:52 14 August

B. Adult 05:52 and Adult/Calf 05:55

C. Adult/Calf 05:55

Compare the intersession variability to Fig. 30 and Fig. 34. n=number of calls.

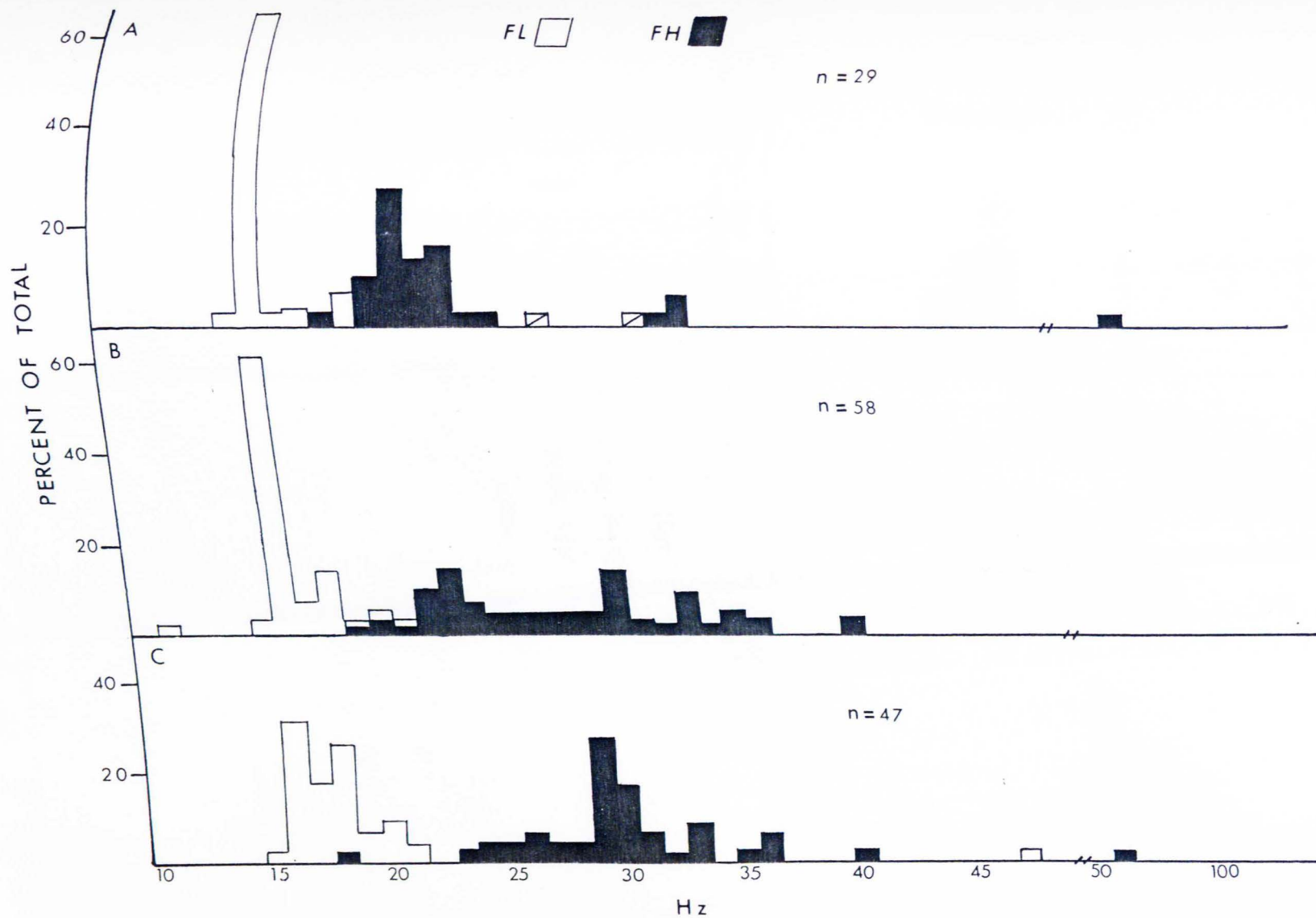


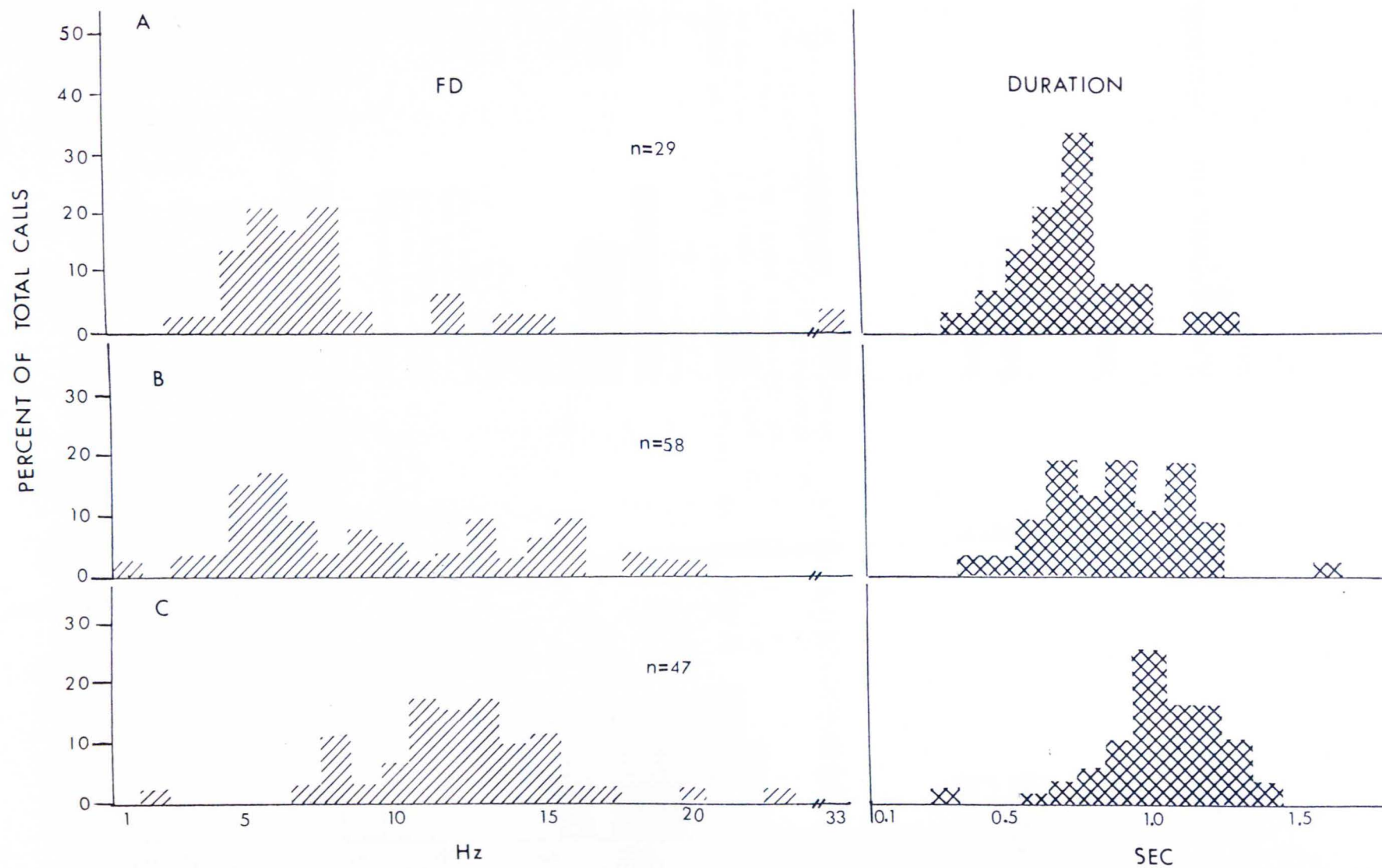
FIGURE 33. Downsweep frequency difference (FD) and duration comparisons for three consecutive sessions involving one to three whales.

A. Adult 05:52 14 August

B. Adult 05:52 and Adult/Calf 05:55

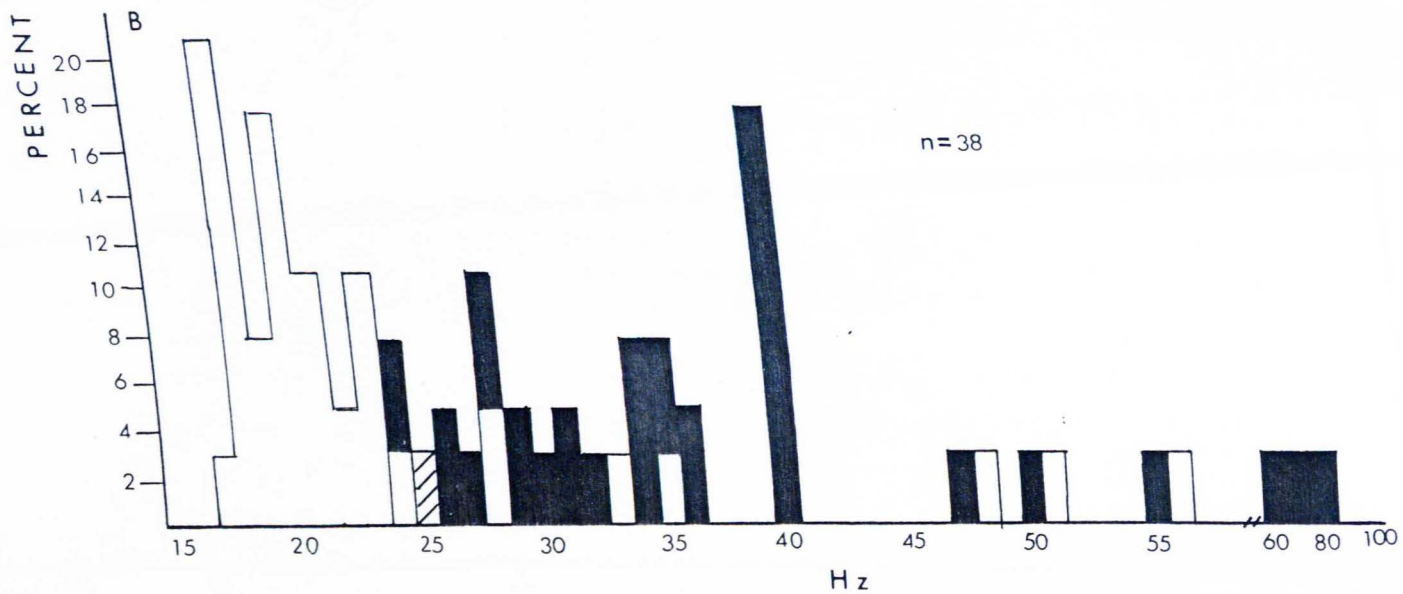
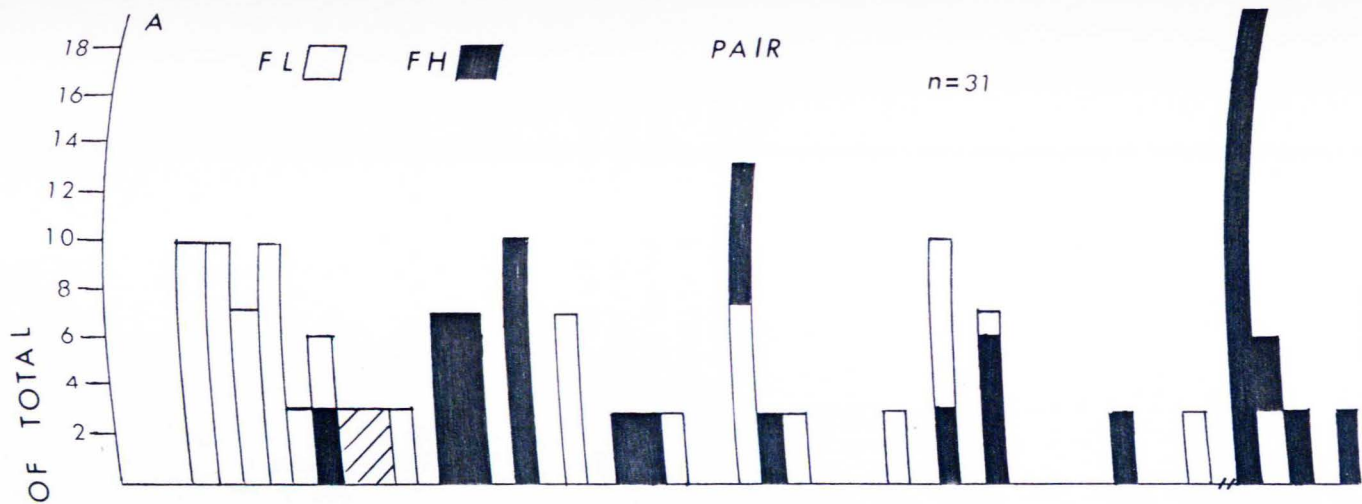
C. Adult/Calf 05:55

n=number of calls



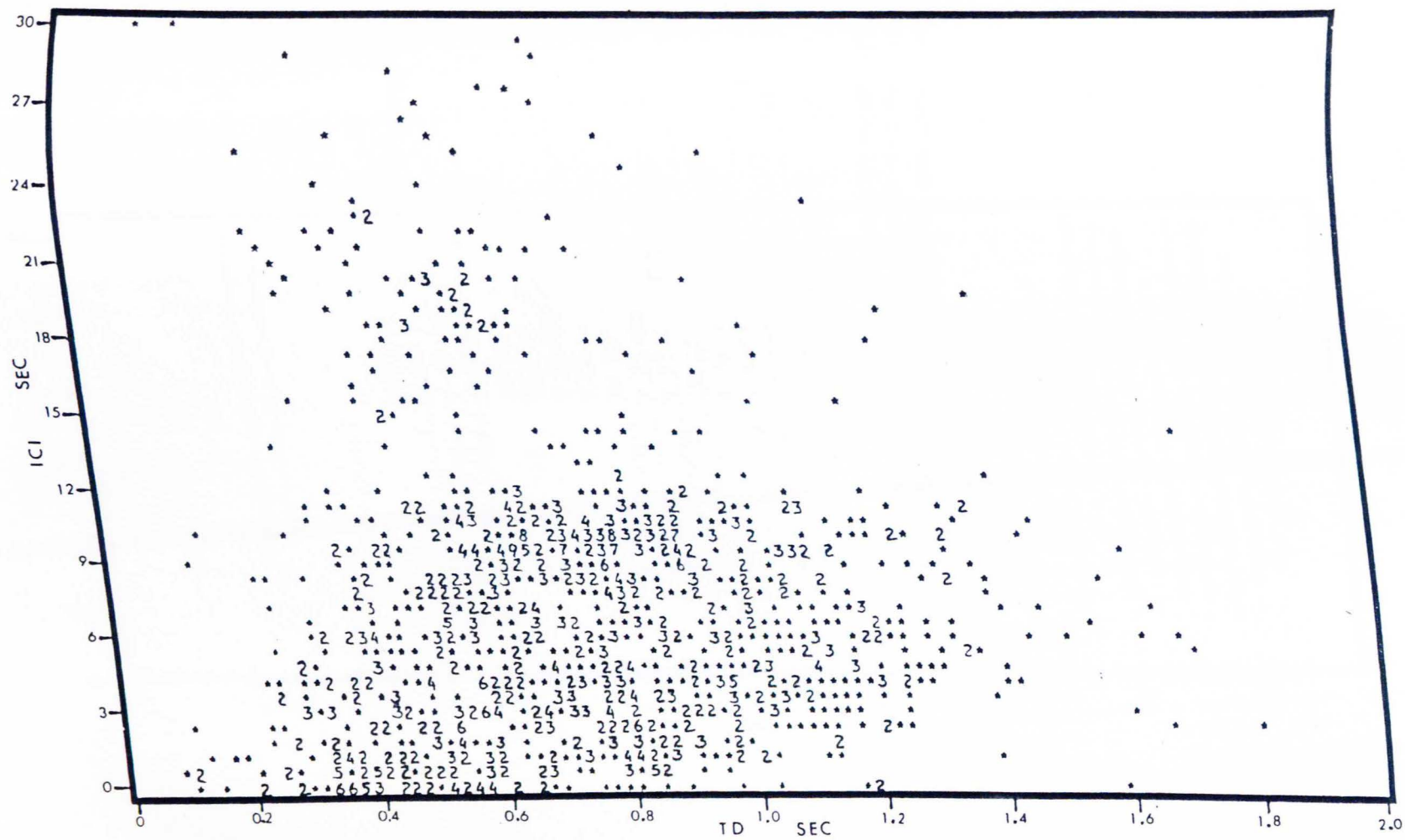
100 a

FIGURE 34. Comparison of subsessions for downsweeps from fin whale pair. FH, frequency high; FL, frequency low; cross-hatching indicates equal percentages for FH, FL. The distributions should be compared to Fig. 31 of the entire session. n=number of calls.



101 a

FIGURE 35. Intercal interval (ICI) and total duration (TD) for all sounds measured. The concentration of ICI values below 12 sec is primarily due to downsweeps. ICI and TD could be measured from sonagrams when noise levels prevented frequency measurements from the real time analyzer screen. n=1537.



102a

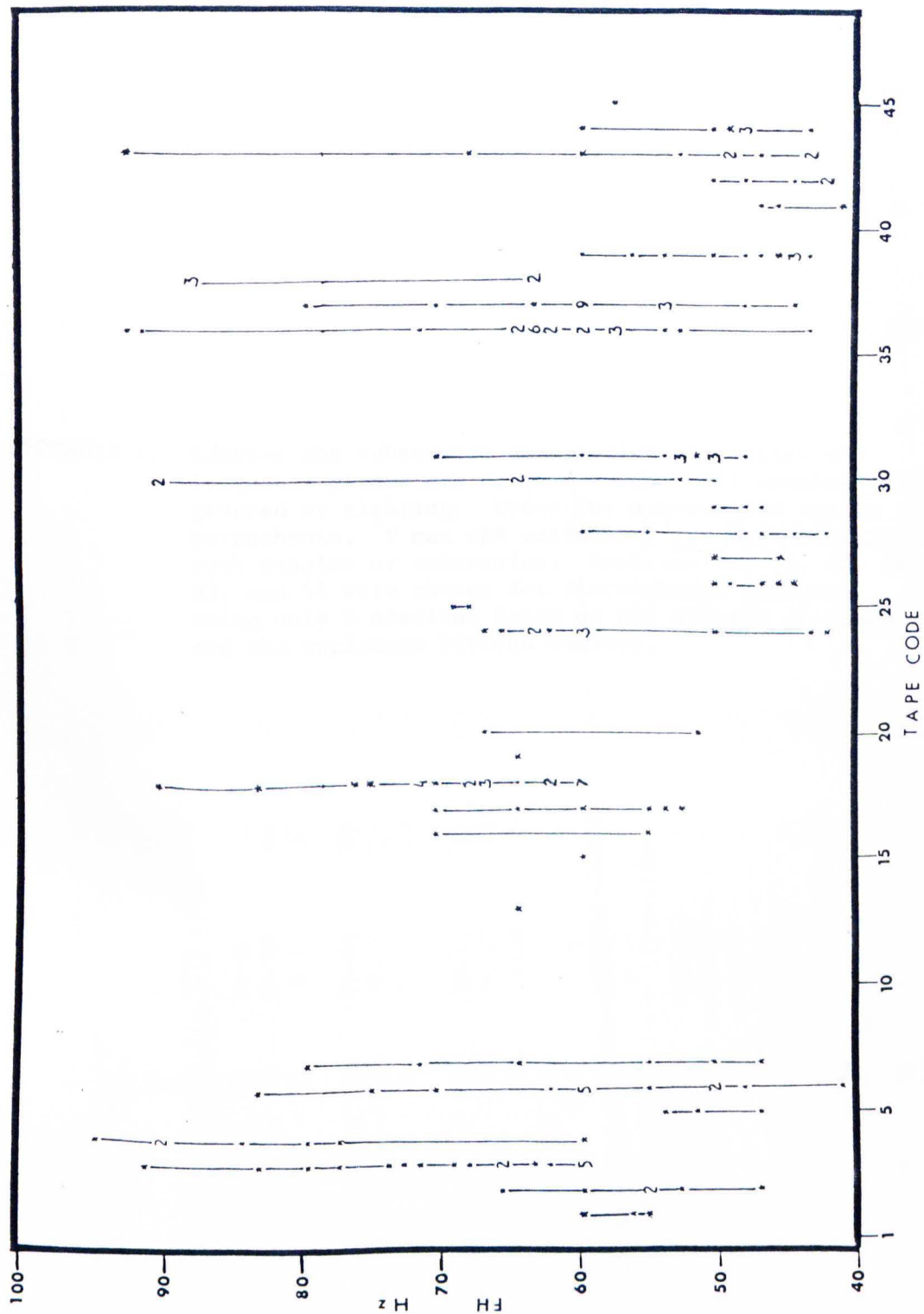
FIGURE 36. Highest frequency (FH) values for lower downsweeps (FI $\leq$ 40) in recording sessions and subsessions. Tape codes correspond to the following sightings:

1-5	2A 08:30, C 10:14	31 July
6-7	2A 06:35	1 Aug
8-9	no source	
10	A 05:27	12 Aug
11-15	A 05:52, A/C 05:55	14 Aug
16	2A 14:26	15 Aug
17-20	A 11:05, A/C 11:10	16 Aug
21-23	A 17:00	16 Aug
24-25	2A 12:20	18 Aug
26-29	A 07:35	19 Aug
30	A 07:53	26 Aug
31-32	A/C 06:24	1 Sept
33-35	2A 15:10+2A 15:28	1 Sept
36-38	4A+minke 17:45+	13 Sept
39-44	A 16:10	15 Sept
45-46	A 16:20, A 16:58, A 17:00, A 17:10	17 Sept

FIGURE 37. Highest frequency (FH) values for higher downsweeps (FI $\geq$ 40) by recording session and subsession. Tape codes correspond to the following sightings:¹

1-5		
6-7	2A 08:30, C 10:14	31 July
8-9	2A 06:35	1 Aug
10	no source	
11-15	A 05:27	12 Aug
16	A 05:52, A/C 05:55	14 Aug
17-20	2A 14:26	15 Aug
21-23	A 11:05, A/C 11:10	16 Aug
24-25	A 17:00	16 Aug
26-29	2A 12:20	18 Aug
30	A 07:35	19 Aug
31-32	A 07:53	26 Aug
33-35	A/C 06:24	1 Sept
36-38	2A 15:10+2A 15:28	1 Sept
39-44	4A+minke 17:45+	13 Sept
45-46	A 16:10	15 Sept
	A 16:20, A 16:58, A 17:00	17 Sept

¹ codes are the same as those used on Fig. 36 and on Fig. 11 of individuals recorded.



APPENDIX I. Session and subsession descriptive statistics for frequency parameters of downsweeps. All sessions are grouped by sighting. Codes for subsessions are in parenthesis. F max was calculated for variables in each session or subsession. Sessions 10, 13, 15, 26, 33, and 41 were chosen for discriminant analysis using only 6 sessions based on the animals recorded and the variances between session.

Session Code	No. of Down- sweeps										Cov. F max S=1	
		f	f Range	Mean	Med	Mode	Var	S.D.	S.E.	C.V.		
1	4	FI	33-60	51	56	33	149	12	6	24	4.96 $\alpha = .01$	
		FF	40-53	47	47	40	33	6	3	13		
		FD	2-15	8	7	2	30	5	3	63		
2	8	FI	34-66	53	54	55	104	10	3	19	13.50 $\neq$	
		FF	26-56	42	41	38	104	10	4	24		
		FD	4-17	10	10	9	18	4	2	40		
3	18	FI	60-92	69	67	60	86	9	2	13	2.09 $\neq$	
		FF	30-80	54	52	52	107	10	2	19		
		FD	10-35	16	14	14	51	7	2	44		
4	7	FI	60-95	82	85	90	136	12	4	15	1.96 $\alpha = .01$	
		FF	38-83	61	58	-	266	16	6	26		
		FD	5-42	21	19	-	227	15	6	71		
5	3	FI	47-54	51	52	47	13	4	2	8	3.25	
		FF	37-43	39	38	37	10	3	2	8		
		FD	10-14	12	11	14	4	2	1	17		
6+7	69	FI	23-107	41	36	40	287	17	2	41	6.67 $\neq$	
		FF	17-78	28	22	18	165	12	2	43		
		FD	1-32	13	13	7	43	7	0.8	54		
6	31	FI	23-107	47	40	60	389	20	4	43	8.84 $\neq$	
		FF	18-78	33	25	18	227	15	3	45		
		FD	3-29	14	13	7	44	7	1	50		
7	38	FI	24-80	37	34	40	166	13	2	35	3.86 $\neq$	
		FF	17-56	24	21	18	84	9	1	38		
		FD	1-32	13	12	8	43	7	1	54		

Session Code	No. of Down-sweeps	f	f Range	Mean	Med	Mode	Var	S.D.	S.E.	C.V.	Cov. F max	S=1
10	14	FI	21-30	26	27	27	4	2	0.6	8	5.00	$\alpha = .05$
		FF	16-19	17	18	17	.8	.9	0.2	6		
		FD	5-11	9	9	9	3	2	0.5	22		
13 ¹	12 ²	FI	19-65	26	23	22	73	9	2	35	5.61	$\alpha = .05$
		FF	15-32	18	16	16	13	4	0.6	22		
		FD	3-27	8	7	6	20	5	0.9	63		
14	59	FI	19-40	27	27	23	27	5	6	19	9.00	$\neq$
		FF	11-21	17	16	16	3	2	0.2	12		
		FD	2-22	10	9	8	23	5	0.6	50		
15	47	FI	18-60	30	29	29	34	6	0.8	20	3.09	$\neq$
		FF	15-47	18	17	16	21	5	0.7	28		
		FD	2-23	12	12	11	11	3	0.5	25		
16	2	FI	55,70	n/a							n/a	
		FF	42,61									
		FD	9,13									
17	6	FI	53-70	60	56	53	47	7	3	12	1.96	$\alpha = .01$
		FF	42-53	47	44	43	24	5	2	11		
		FD	6-22	14	12	12	43	7	3	50		
18	26	FI	60-90	68	67	60	62	8	2	12	1.20	$\alpha = .01$
		FF	28-65	46	46	40	84	9	2	20		
		FD	6-37	21	20	20	73	9	2	43		
19	1	FI	65	n/a							n/a	
		FF	51									
		FD	14									

¹Sessions 11 and 12 could not be measured due to noise.

²Only 12/29 could be measured out of noise

Session Code	No. of Down-sweeps	f	f Range	Mean	Med	Mode	Var	S.D.	S.E.	C.V.	Cov. F max	S=1
20	2	FI FF FD	52,67 40,48 12,19	n/a							n/a	
21-23	111	FI FF FD	22-36 16-23 4-16	27 18 9	27 18 9	28 18 10	5 1 4	2 1 2	0.2 0.1 0.2	7 6 22	5.00	≠
(21)	42	FI FF FD	23-30 16-20 6-12	27 18 9	27 18 9	26 18 8	4 .7 2	2 .8 2	0.3 0.1 0.2	7 4 22	5.71	≠
(22)	38	FI FF FD	22-36 17-23 5-16	27 18 9	27 18 9	28 18 10	6 2 5	3 1 2	0.4 0.2 0.4	11 6 22	3.00	≠
(23)	31	FI FF FD	22-33 16-20 4-13	27 18 9	26 18 9	26 18 9	5 .6 4	2 .8 2	0.4 0.1 0.4	7 4 22	8.33	≠
24	29	FI FF FD	25-118 10-81 4-37	45 33 14	37 27 14	60 20 10	399 227 59	20 15 8	4 3 1	44 45 57	6.76	≠
25	2	FI	68,69 50,53 16,18	n/a							n/a	
26-28	126	FI FF FD	20-60 16-45 3-28	29 20 9	26 18 8	23 18 6	251 240 21	16 16 5	1 1 0.4	55 80 56	11.95	≠

Session Code	No. of Down-sweeps	f	f Range	Mean	Med	Mode	Var	S.D.	S.E.	C.V.	Cov. F max	S=1
(26)	42	FI	23-51	30	28	23	57	8	1	27	7.13 $\neq$	
		FF	16-40	21	18	18	42	7	1	33		
		FD	4-16	9	8	8	8	3	0.4	33		
(27)	40	FI	21-50	28	26	23	37	6	1	21	2.64 $\alpha = .05$	
		FF	16-45	19	18	18	21	5	0.7	26		
		FD	4-24	8	8	6	14	4	0.6	50		
(28)	43	FI	20-60	29	26	24	88	9	1	31	4.4 $\neq$	
		FF	16-40	20	18	18	20	5	0.7	25		
		FD	1-28	9	6	6	33	6	0.9	67		
29	u ³		n/a								n/a	
30	6	FI	50-91	69	65	65	315	18	7	26	9.54 $\alpha = .01$	
		FF	28-60	43	40	40	167	13	5	30		
		FD	16-32	26	25	25	33	6	2	23		
31	40	FI	21-70	31	22	21	226	15	2	48	10.76 $\neq$	
		FF	16-55	24	17	17	142	12	2	50		
		FD	1-19	7	4	4	21	5	0.7	71		
32	18	FI	21-30	23	23	23	5	2	0.5	9	4.00 $\neq$	
		FF	12-18	17	18	18	2	2	0.4	12		
		FD	3-13	6	5	3	8	3	0.7	50		
33-35	117	FI	20-40	26	25	24	10	3	0.3	12	3.33 $\neq$	
		FF	17-27	19	19	18	3	2	0.2	11		
		FD	2-13	6	6	6	6	2	0.2	33		
(33)	45	FI	22-40	26	25	25	11	3	0.5	12	2.20 $\alpha = .05$	
		FF	18-27	20	19	21	5	2	0.3	10		
		FD	3-13	6	6	4	5	2	0.3	33		

³
u=unknown structure

Session Code	No. of Down-sweeps	f	f Range	Mean	Med	Mode	Var	S.D.	S.E.	C.V.	Cov. F max	S=1
(34)	43	FI	21-33	25	24	24	9	3	0.4	12	3.00 $\neq$	
		FF	18-25	19	18	18	3	2	0.3	11		
		FD	2-12	6	6	6	5	2	0.4	33		
(35)	29	FI	21-30	25	24	23	8	3	0.5	12	4.00 $\neq$	
		FF	17-23	19	18	18	2	1	0.3	5		
		FD	3-13	6	6	5	6	2	0.5	33		
36	47	FI	17-93	42	25	28	431	21	3	50	9.17 $\neq$	
		FF	16-80	31	18	18	298	17	3	55		
		FD	2-31	12	10	7	47	7	1	58		
37	29	FI	25-80	49	60	60	268	16	3	33	2.95 $\alpha = .05$	
		FF	18-60	31	31	18	103	10	2	3		
		FD	6-35	18	21	8	91	10	2	6		
38 ⁴	27	FI	20-88	34	25	26	480	22	4	65	96.00 $\neq$	
		FF	16-86	27	17	18	486	22	4	82		
		FD	2-11	7	8	8	5	2	0.4	29		
39-40	55	FI	19-60	35	32	40	78	9	1.2	26	3.12 $\neq$	
		FF	18-40	26	25	25	27	5	0.7	19		
		FD	2-22	10	9	8	25	5	0.7	50		
(39)	32	FI	23-60	38	40	40	94	10	2	26	3.13 $\neq$	
		FF	21-40	28	28	21	30	5	1	18		
		FD	2-22	11	11	5	30	6	1	55		
(40)	23	FI	19-40	31	31	28	31	6	1	19	3.44 $\alpha = .05$	
		FF	18-27	23	23	20	9	3	0.6	13		
		FD	2-19	9	8	8	16	4	0.8	44		

⁴This session was deleted from any further analysis due to the extremely high F max.

Session Code	No. of Down- sweeps	f	f Range	Mean	Med	Mode	Var	S.D.	S.E.	C.V.	Cov.	
											F max	S=1
41-44	166	FI	19-93	31	28	23	103	10	0.8	22	3.55 ≠	
		FF	15-80	21	19	18	52	7	0.6	33		
		FD	1-30	10	8	7	29	5	0.4	50		
(41)	40	FI	20-47	29	29	31	37	6	1	21	3.08 ≠	
		FF	17-38	20	19	18	12	3	0.6	15		
		FD	1-20	9	8	8	23	5	0.8	56		
(42)	41	FI	20-50	30	29	23	58	8	1	27	3.87 ≠	
		FF	15-30	20	19	20	15	4	0.6	20		
		FD	2-20	10	8	7	21	5	0.7	50		
(43)	44	FI	19-93	32	28	23	204	14	2	44	6.00 ≠	
		FF	15-80	22	18	16	136	12	2	55		
		FD	3-30	10	9	7	34	6	0.9	60		
(44)	41	FI	19-60	32	27	26	96	10	1.6	31	3.09 ≠	
		FF	16-45	21	19	18	31	6	0.9	29		
		FD	3-26	11	8	6	39	6	1	55		
45	52	FI	21-57	26	25	26	28	5	0.7	19	3.11 ≠	
		FF	16-44	18	16	16	16	4	0.6	22		
		FD	5-20	9	8	8	9	3	0.4	33		
46	36	FI	22-36	28	27	27	7	3	0.5	11	10.00 ≠	
		FF	16-18	17	17	18	.8	.9	0.2	5		
		FD	4-18	11	10	10	8.1	2.8	0.5	25.4		

APPENDIX II. Listing of calling rates (calls/min) for all recordings made between 28 June - 27 September in the presence of fin whales.

Fin Whale	Time	Date (1979)	Calls (n)	Total Time (min)	Rate (n/min)	Behavior	Comments
A ¹	05:06	28 June	0	10.0		Arcing	Brief Rumble
2A	05:30		0	30.0			
A	09:18	13 July	0	15.0		Straight	
2A	19:07	13 July	0	3.0		Straight	Rumble
A	6:07 (+Minke)	14 July	0	8.0		Straight	Rumble
A	8:12	14 July	3	13.0	0.2	Straight	
J ²	9:14 (+Minke)	14 July	0	8.0		Straight	
A	16:57 (+Minke)	14 July	0	7.0		Straight	
A	13:03 (+Minke)	21 July	0 0	26.0 26.0		Straight	
A	08:09	28 July	0	33.0		Active Arcing	
A	10:10 (+Minke)	28 July	0	10.0		Straight	Over 1.5 km away
A/C ³	17:30	28 July	0	15.0		Straight	C very small

¹A=Adult, ²J=Juvenile, ³C=Calf

Fin Whale	Time	Date (1979)	Calls (n)	Total Time (min)	Rate (n/min)	Behavior	Comments
A	14:24	29 July	0	10.0		Straight	Same as 08:09 28 July
2A	08:30	31 July	8	18.0	0.4	Arcing	
			12	25.5	0.5		
			22	22.0	1.0		Rumble
			12	27.0	0.4		Rumble
+C	10:14		3	21.0	0.1	Active	Rumble

Fin Whale	Time	Date (1979)	Calls (n)	Total Time (min)	Rate (n/min)	Behavior	
2A	06:35	1 Aug	94	23.0	4.1	Straight	Rumble
A	05:27	12 Aug	16	12.5	1.3	Active	Ferry whale watching
A	05:52	14 Aug	32	32.0	4.0	Active	
A/C	05:55		13	3.0	4.3		
			28	22.0	1.3		
			65	16.0	4.1		
			58	9.0	6.4		
2A	14:26	15 Aug	5	14.5	0.3	Straight	
A	07:14	16 Aug	(24)	(5.5)	(4.4)	Straight	Too faint to analyze (heard on rewind)
A	11:05	16 Aug	16(72)	14.0	1.1(5.1)	Arcing	(more heard on rewind)
A/C	11:10		36	27.5	1.3	Active	
			2	33.0	0.1		
			3	15.0	0.2		
A	17:00	16 Aug	132	24.0	5.5	Straight	
A/C	11:21	17 Aug	0	9.5		Active	
C	12:16		0	6.0		Straight	
2A	12:20	18 Aug	27	14.0	1.9	Active	Chased by boat
			3	10.5	0.3		
A	07:35	19 Aug	21	10.0	2.1	Straight	

Fin Whale	Time	Date (1979)	Calls (n)	Total Time (min)	Rate (n/min)	Behavior	Comments
A	09:48	20 Aug	0	13.0		Straight	
A	07:53	26 Aug	14	16.0	0.1	Straight	Rumble
A/C	06:24	31 Aug	55 18	13.0 3.5	4.2 5.1		
2A	15:10	1 Sept	159	32.5	4.9	Active	
2A	15:28 (+ Minkes)	1 Sept	159	32.5	4.9	Active	
4A	17:45	13 Sept	159	16.0	9.9	Active	
A	16:10	15 Sept	83 207	11.5 23	7.2 9.0	Straight	
A	16:20	17 Sept	60	4.5	13.3	Missing	High wave conditions may be whales. Partial analysis.
A	16:58		60	4	15.1		
A	17:00						
A	17:10						

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