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The effects of boat noise on vocal behavior of *Orcinus orca* as an indication of their ability to adapt to human activities in Canadian waters

by
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In partial fulfillment of the requirements for the Bachelor of Arts in Biology.

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Dedicated to the memory of Mike Bigg

Errata

Several gramatical errors were discovered by Naomi Rose after this paper had been submitted to the Biology Board at UC Santa Cruz. She also helped me to make clearer a few ambiguous sentences. Aside from the various corrected gramatical errors throughout the paper, and the sentence and word changes indicated below, this paper is identical to that which is on file at the Biology Board at UCSC. No numbers or results have been altered.

page 1, paragraph one: "...to seemingly small..." --> "...to seemingly mild..."

page 4, paragraph 2: "...rarely whistle and call." --> "...occasionally whistle and call."

page 9, paragraph 1: "...encounters for socialization..." --> "...encounters of socializing..."

page 9, paragraph 3: "Then the SCRs were separated..." --> "SCRs were also separated..."

page 11, paragraph 3: "...presence of boats have..." --> "...number of boats has..."

page 12: all "percentages" were changed to "proportions"

page 12, paragraph 2: "...would thought to be increased, which it is across..." --> "...would be expected to increase in this study which it did across..."

page 13: "...calls is to replace another more often utilized call type." --> "...calls replaces other more often utilized call types."

page 14: "The simplest answer is that..." --> "This simplest answer to the whales' apparent lack of reaction to engine noise is that..."

Introduction

Increasing evidence indicates that human-created underwater noise may adversely affect marine mammals. Sensitivity to boat noise varies across cetacean species, ranging from extremely negative reactions in the Arctic beluga and narwhal where avoidance behaviors start when icebreakers are in excess of 40 kilometres away (Cosens et al. 1986), to seemingly mild as in finbacks and right whales of the Cape Cod waters. According to Watkins (1986), finbacks and right whales of Cape Cod waters became accustomed to boat noise over a twenty-year period. But even though right whales and finback whales have ceased to actively avoid boats, they still fall silent when acoustically disturbed.

Boats are clearly advantageous to humans in order to utilize the sea; however, the engine noise may pose problems to the marine mammals that rely upon sound for their food, orientation and kin recognition. Research in cetacean communication has revealed how dependent upon sound cetaceans are. One population, the northern resident killer whales of British Columbia, recently fell under acute observation when biologists found how easily accessible they are. This accessibility also centers the whales in a fishing, logging and whalewatching community. Studies done by Briggs (1991) and Kruse (1984) indicate that the presence of boats adversely affects the orientation behavior of these whales.

Though studies of vocal behavior of the northern resident pods have been going on for over ten years, none have been conducted on noise pollution in the orcas' environment and how it affects their vocal behavior. As a result, conflicting impressions are now arising from the whale watchers, researchers and residents in the Johnstone Strait area as to the effects of boat noise on the whales.

Without their communication system, these whales could easily lose each other in the catacombed inlets of the inside passage. It's possible that their unique pod dialects allow the whales to stay in touch, both when separated by kilometres (up to twenty) during traveling and foraging, and when intermixed with other whales of different family groups (Ford 1981). Their dialects could serve to preserve the family group and prevent inbreeding.

Every orca now living in the northern resident population has virtually grown up with engine noise. Since they continue to frequent these "loud" areas during the season of highest boat concentration, it seems likely they have adapted to the engine noise in some way. This study was conducted at a time and place where orcas and boats frequently coincide in hopes that their ability to acoustically adapt to the presence of high levels of boat noise could be inferred through their vocal behavior.

The Study Animals

The northern resident orcas of British Columbia frequent the northern Johnstone Strait along the inside passage of northern Vancouver Island and surrounding areas during the summer months. The population consists of sixteen pods of approximately 190 individuals (Bigg et al. 1987). The orcas travel in stable pods of family groups, usually a female and her offspring, and consist of adult and juveniles of both sexes (Bigg et al. 1987). A set of discrete calls, with dialects unique to each pod, appear to be used to keep in acoustic contact when the orcas are spread out during traveling and foraging (Bigg et al. 1987).

Ford (1982) classified the orcas' behavior into 'active' and 'inactive' and found that in most cases, the degree of vocal activity corresponded to the degree of behavioral activity. As behavioral activity increases, the calls per whale per minute generally increase. Foraging, traveling, rubbing, and socializing are considered 'active' behaviors and call rates vary up to fifty calls per minute depending on the number of whales present. The orcas can be either continuously vocal or alternate periods of varying vocality and silence. Resting is an 'inactive' behavior. Resting behavior is quieter than the 'active' behaviors but whales may still occasionally whistle and call.

Materials and Methods

The study area was located in the Johnstone Strait, British Columbia, on the inside passage between Vancouver Island and the mainland of Canada (Figure 1). The station was located on a one-hundred metre long smooth stone beach about eight nautical miles east of Telegraph Cove. The research was strictly shore-based, waiting for the orcas to swim close to shore and the hydrophone, which they did from seven times a day to once a week.

Data taken included sighting number, tape number, date, time, subpod(s), total number of whales, location, direction of travel, behavior, formation, visual and/or vocal identification, whether or not boats were present, their approximate distances from the whales, and a general impression as to whether or not the whales were vocal.

The vocalizations and boat noise were recorded on an uncalibrated Navy surplus, sonar-point, hypoxy-type hydrophone #2590, anchored near 65 feet of depth at the highest tides. Tides fluctuated from -0.2 low tides to +16.8 high tides. The hydrophone was set at high tide using SCUBA and retrieved by pulling in the cable from a kayak. The entire system needed no maintenance for the duration of the study. Approximately 500 feet of cable was laid, also using SCUBA, onto the sea floor. To keep the tides and currents from moving the cable, it was anchored with rocks under water, and buried on the beach approximately one foot deep, spanning the 20 feet from low tide line to the camp.

With a mini-phone plug terminal, the cable hooked into a mono-hydrophone box model M9VL (the hydrophone, cable and hydrophone box were purchased through Paul Spong, Orca Lab, Hanson Island). A mini-phone plug adaptor connected one end of an RCA cable to the mono-hydrophone box and the other end of the RCA cable led into the right channel of a Sanyo C9 portable mini component system. Its power supply was one of four 12V batteries. A DC adaptor with the cigarette lighter adaptor end removed (personal mutation) was used to hook the stereo system directly to the car battery terminals. Two realistic 3" speakers provided instantaneous sound.

The orcas were recorded on the right channel and simultaneous voice notes using a Realistic Highball-7 (#33-986B) microphone accompanied each recording on the left channel. The Sanyo C9's settings were as follows: metal on, dolby off, loudness off; input stayed on 6 for the orca channel and 10 for the microphone channel.

The data analysis was done with a Digital Signal Analysis Language program, version 2.8 by Engineering Design (43 Newton Street, Belmont, Massachusets). Levels of boat noise and surrounding sounds were measured by relative amplitude on a power spectrum using voltage readings of the output. Since recordings were only made when the orcas were near the hydrophone, the boat noise on the tape is an adequate representation of what the orcas were being exposed to. Levels of relative amplitude ranged from 0.01V representing ambient noise levels with no boats, to 3.0V representing a purse seiner directly over the hydrophone. Decibels were not used because the limited funding for the project did not allow for equipment sufficient for calibration.

Boat noise ranged from 0 Hz and generally stayed below 3000 Hz (Figure 2), while the orca calls ranged from about 500 Hz to 8000 Hz (Figure 3), limited only by the sensitivity of the hydrophone. Thus calls could be counted and identified quite easily by use of the spectragram (Figure 4). Since samples were taken only when the whales were within 1500 metres of the hydrophone, intensity of the calls in comparison to the boat noise was rarely an issue.

Vocality was calculated using the following formula suggested by John Ford (personal communication): Standard Call Rate =

(#calls/#whales)/ minute. Amplitude was measured at one minute intervals or shorter defined by slight detectable changes in the levels. A Standard Call Rate (SCR) was calculated for each interval and recorded alongside the corresponding engine amplitude level.

Results

The study lasted 54 days from July 2 to August 24, 1990. The 17 subpods of orcas, representing nine pods and totaling 77 orcas included in the study were positively identified both visually using a photo-identification book (Bigg et al. 1987) and acoustically by experience and comparison with a reference tape (Ford, Spong, unpublished tapes). Encounters lasted from five minutes to two hours. Total time of data analyzed was 16 hours and 39 minutes. Behaviors encountered included resting, foraging, traveling, socializing and beach rubbing. Due to few encounters of socializing and beach rubbing, only traveling, foraging and resting behaviors were used.

Behaviors were spread throughout different levels of boat noise (Figure 5). No behavior dominated at either end of the amplitude.

All calculated SCRs were paired with their corresponding level of boat noise and graphed in a general regression (Figure 6). There was no correlation between the level of boat noise and SCR. SCRs were also separated by behavior and once again graphed with the corresponding levels of boat noise. Neither traveling (Figure 7), foraging (Figure 8) nor resting (Figure 9) showed any significant correlation of SCR with boat noise levels.

Sudden changes in the intensity of boat noise were looked at to see if they affected the SCR. A two-way ANOVA test, uneven observations per cell, was run with SCR for high and low levels of vocal activity, and compared with sudden medium and high changes in boat noise levels (n=125). These sudden changes in boat noise did not correlate in any way to changes in the SCR of the whales.

Results for the A30 subpod were also studied separately for signs of pod specificity using both the SCR and variAnce in discrete call usage in relation to amplitude of boat noise. They were the pod on which the most data had been collected. The A30's showed no significant correlations between relative amplitudes and SCR (Figure 10). The greatest differences in discrete call usage (based on Ford 1984) across levels of amplitude were shown in the N1, N2, N3 and N47 calls (Figure 11).

Discussion

This preliminary study indicates that boat noise has no detectable effect on the SCRs of the northern resident orcas. They do not appear to be startled by sudden changes in boat noise nor is there evidence that they cease vocalizing when levels of boat noise get to a certain level. The orcas showed all three behaviors in relative proportions at both low and high levels of boat noise.

The whales did not seem to avoid the boats creating the noise and went so far as to swim under the net of a gill netter setting very close to our beach. They were also observed to swim very close to the stern of certain boats such as the M.V. *Lukwa* of Telegraph Cove, a whale watching boat the whales are familiar with.

These whales seem to have adapted to the presence of boats in the Johnstone Strait, which should not seem all that suprising since all of the whales alive today have lived their entire lives with boats and the subsequent boat noise. It is true that the number of boats has increased in the past ten years and there may be more subtle effects that a larger set of data could detect. There may also be other factors such as type of boat which this study did not address. But high amplitude levels were not shown to affect the SCR.

Looking at a specific pod, the A30's, a subpod of six orcas that frequents the Johnstone Strait for the majority of the summer, also turned up no evidence that high levels of boat noise affect the SCR. Not enough data were available to test a pod that uses the area less often than the A30s.

Frequency of usage of discrete call types in relation to boat noise levels does show some differences from a previous study (Ford 1984). During traveling behavior, four call types (N1, N2, N3, and N47) were seen in different proportions than in Ford's results. Ford's study included three pods of whales, A1, A4, and A5, whereas this portion of the study included only A30's, a subpod of the A1 pod. The N47 call is used exclusively by the A1 pod and not the A4's and A5's. So the frequency of its use would be expected to increase in this study, which it did across all three amplitude classes. N3 was also found in greater proportion than would be expected in all but the middle category of amplitude classes. N3 is normally used during resting and it is possible that rest was combined with or confused with slow travel. The last two calls, N1 and N2, appear out of proportion in only one category of amplitude levels, level three and level two, respectively. Looking at the call structure from a physics standpoint could discover a reason for this anomoly. Perhaps these calls are easier to detect at those levels of engine noise than other calls are. But there is also no evidence that an increase in those calls replaces other, more often utilized call types. The small sample size is most likely skewing the results. A much larger sample size for a specific pod at differing levels of boat noise would be needed to detect significant differences in discrete call type usage.

Conclusion

There is no evidence linking underwater noise levels to the SCRs of the northern resident killer whales in the Johnstone Strait. There is limited evidence to suggest that the whales may be altering discrete call type usage to fit the noise environment in which they are communicating. This aspect deserves further research. In both cases, they seem to have adapted to the presence of increased boat noise in their environment.

The simplest answer to the whales apparent lack of reaction to engine noise is that their auditory range extends beyond what boats put out into the water which is usually contained below 5000Hz. Call frequencies of the orcas range well beyond 10000Hz. Their calls are most likely transmitting without interference above those levels that could be acoustically masked or altered by the boat noise.

Acknowledgements

I would like to thank all those who made this project possible. Tanya Kjeldsberg must be first and foremost for putting up with me as we both collected data on a lonely beach in the Johnstone Strait. Dave Arcese and the Northern Lights Kayak Tours provided a kayak and tarps and companionship. Jim and Anne Borrowman, Bill and Donna MacKay and the rest of Stubbs Island Charters brought us mail and batteries and leftovers from the whalewatchers' lunches and provided transportation of us and our gear to and from the beach. Paul Spong and Helena Symonds initiated me into the world of cetacean research, facilitated the purchase of the hydrophone and cable and supported this project from the very beginning.

Special thanks to my advisor Burney Le Boeuf, to John and Bev Ford for their advice, support and backup hydrophone, to David Bain of Marine World/Africa, USA for his patience with my presence, and the use of his computer to analyze the data and to Marshall Sylvan for help in the statistical analysis. I also must thank the Student Activities Office and Biology Board of UCSC, and William and Judy Layman for providing partial funding for this study. This project would not have happened without the help and guidance of these people. Thank you all.

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Figure 1. Map of study area. Johnstone Straits, British Columbia, Canada. The x (126°43'W 50°31.5'N) marks the hydrophone location and the triangle shows the distribution range of whales during the recording.

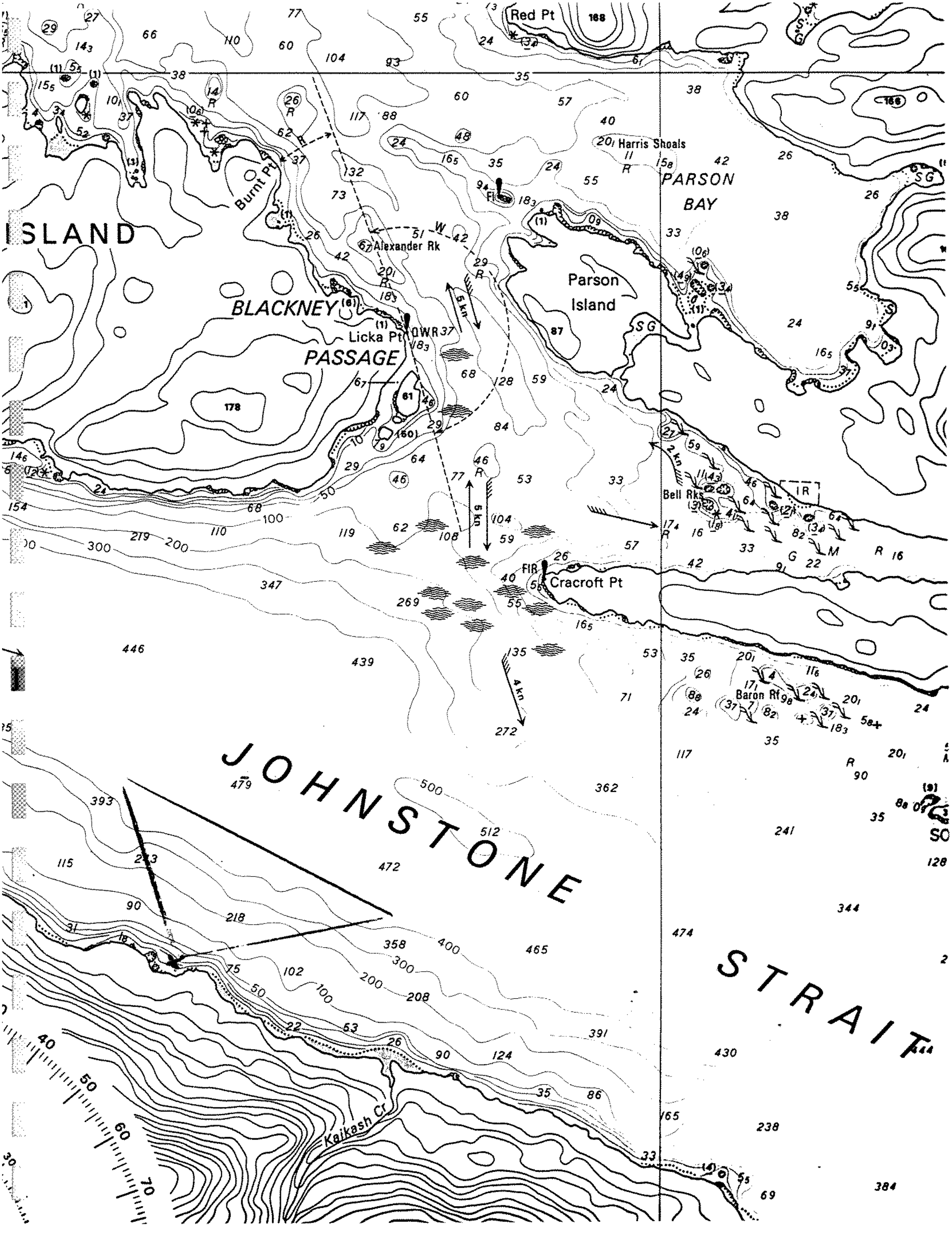
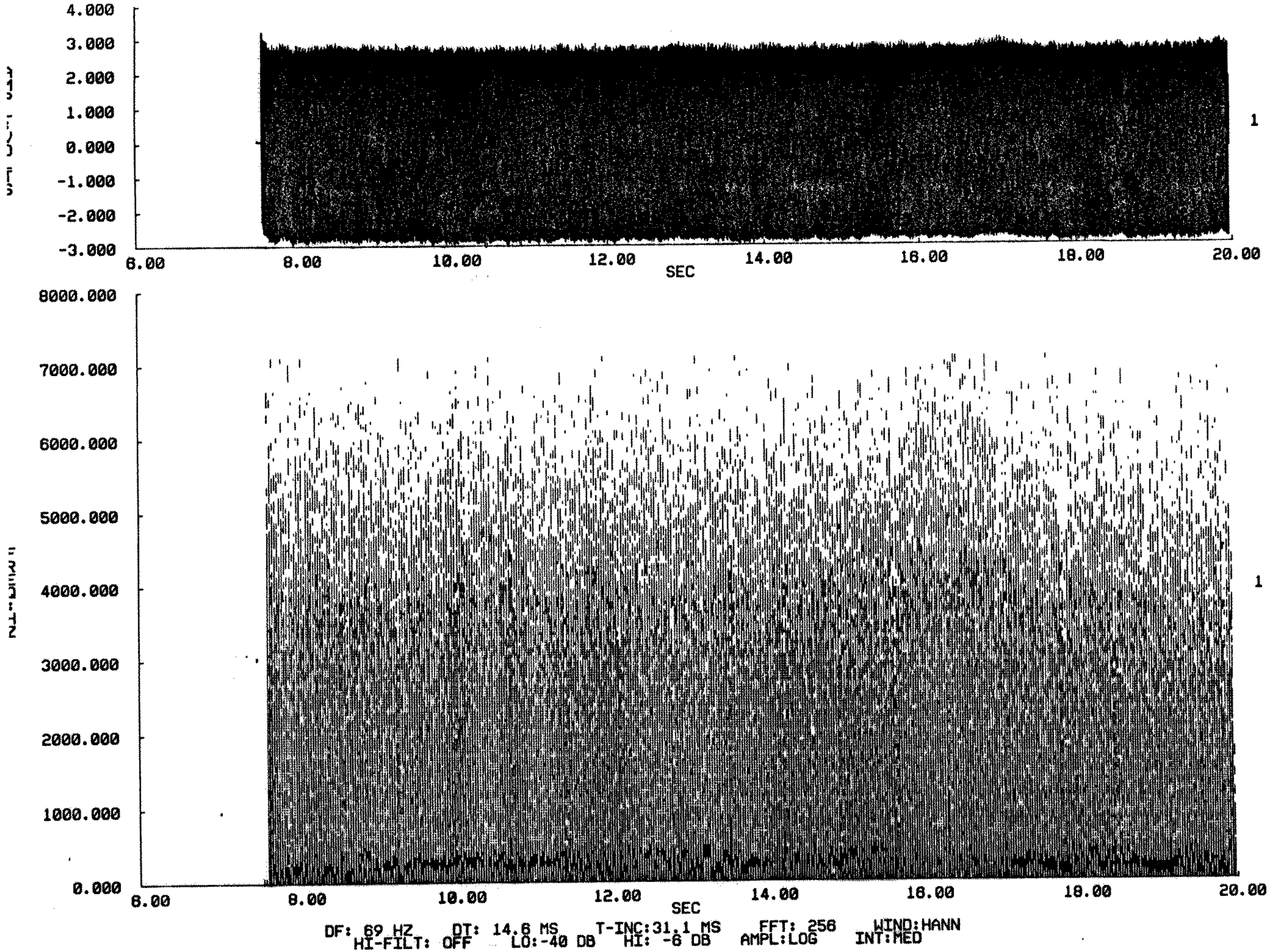

Red Pt
Harris Shoals
PARSON
BAY
ISLAND
Burnt Pt
Alexander Rk
Parson
Island
BLACKNEY
Licka Pt
PASSAGE
Bell Rks
Cracroft Pt
Baron Rf
JOHNSTONE
STRAIT
Kaikash Cr

Figure 2. Frequency spectragram of the engine noise of a purse seiner in the Johnstone Strait at 2109 hours, August 24, 1990. The sample was taken in the presence of the resting D pod but in the absence of whale vocalizations. Relative amplitude of engine noise is 3.0V.



4.000
3.000
2.000
1.000
0.000
-1.000
-2.000
-3.000
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
SEC
1
8000.000
7000.000
6000.000
5000.000
4000.000
3000.000
2000.000
1000.000
0.000
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
SEC
1
DF: 69 HZ DT: 14.6 MS T-INC:31.1 MS FFT: 256 WIND:HANN
HI-FILT: OFF LO:-40 DB HI: -6 DB AMPL:LOG INT:MED

Figure 3. Frequency spectragram of a discrete call (N4) produced by A30 subpod during foraging behavior taken at 1649 hours on July 19, 1990. Amplitude of underwater noise levels is 0.05V (no boat noise).

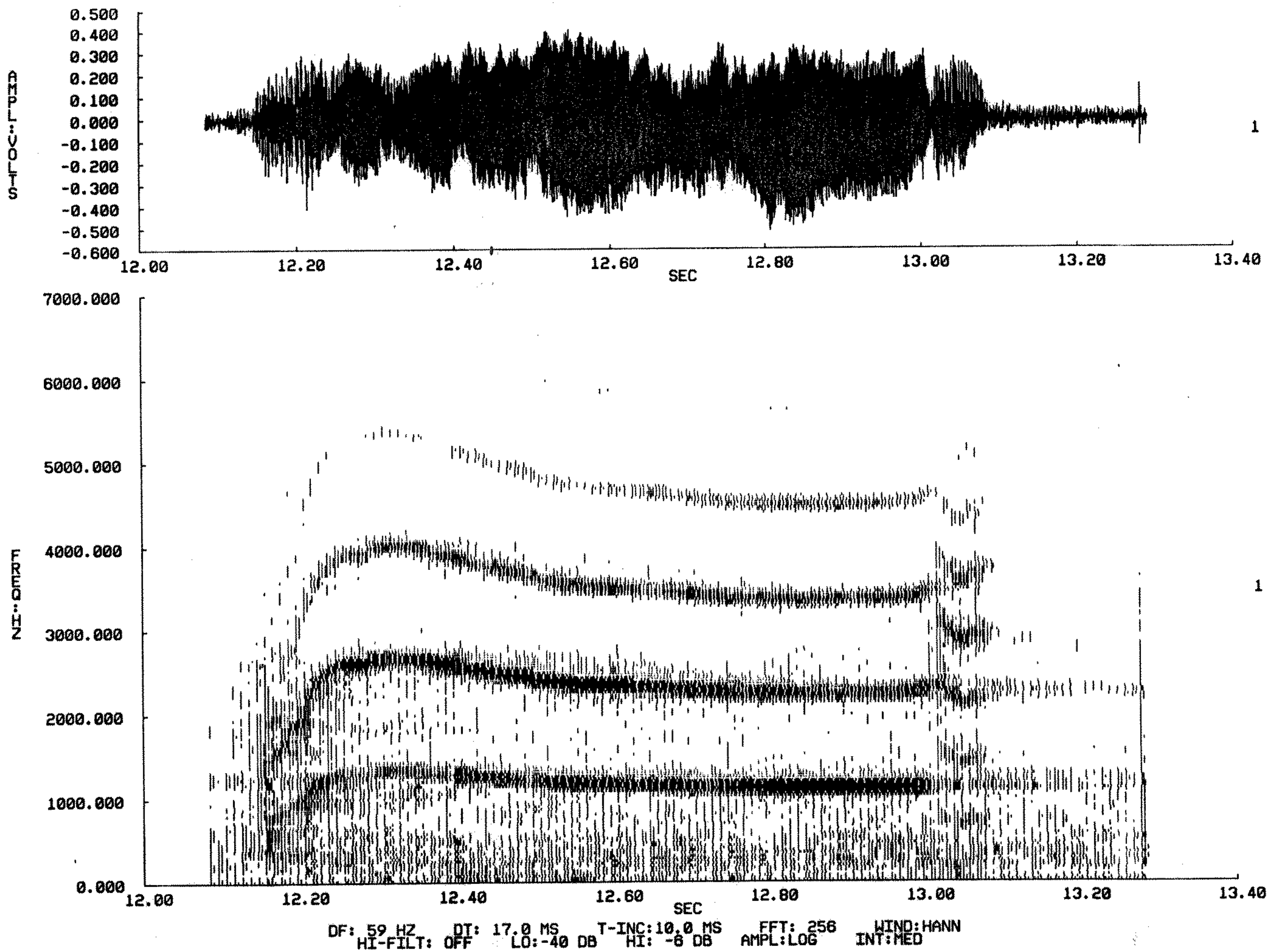
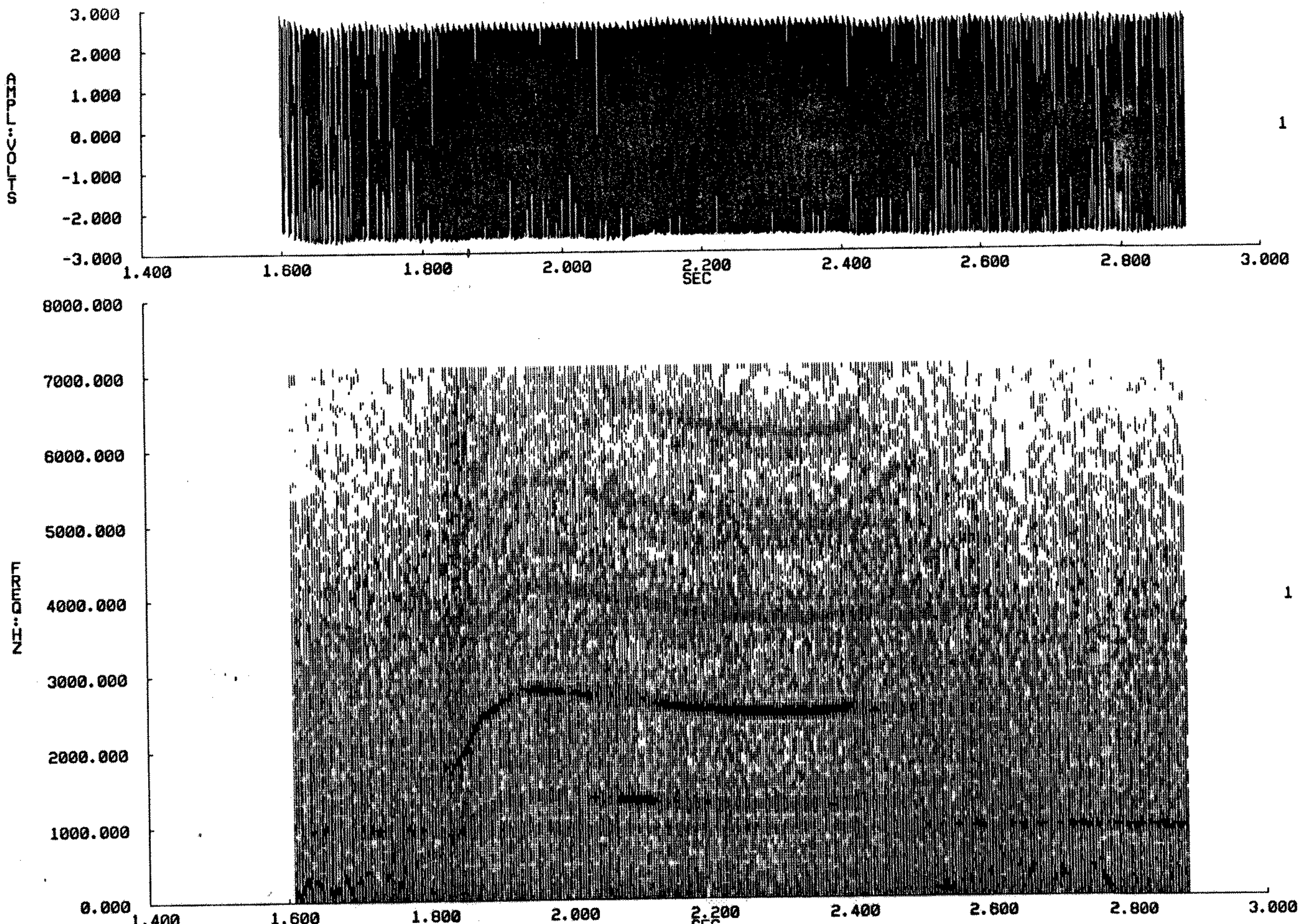
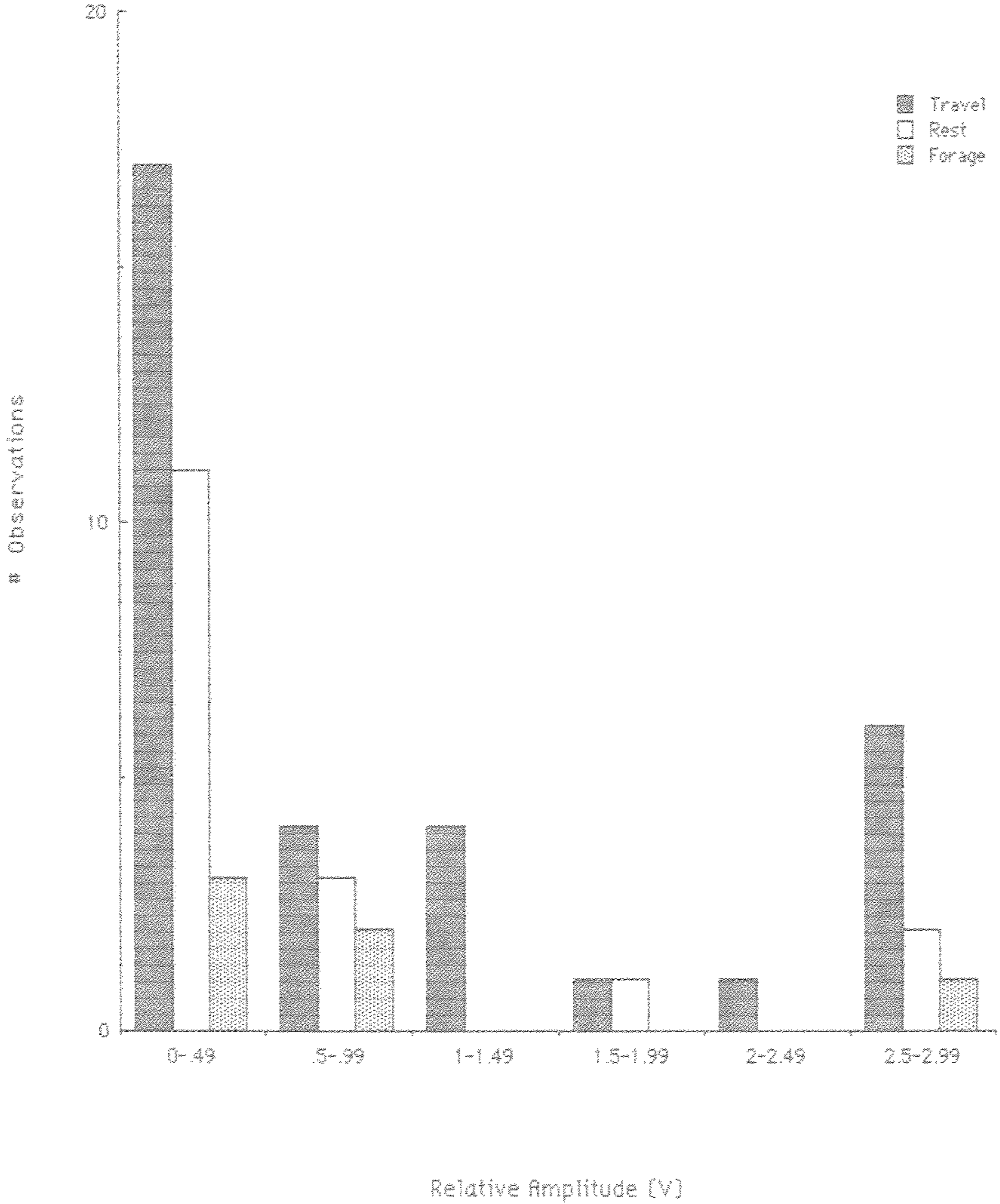

AMPL:VOLTS
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-0.300
-0.400
-0.500
-0.600
12.00 12.20 12.40 12.60 12.80 13.00 13.20 13.40
SEC
1
FREQ:HZ
7000.000
6000.000
5000.000
4000.000
3000.000
2000.000
1000.000
0.000
12.00 12.20 12.40 12.60 12.80 13.00 13.20 13.40
SEC
1
DF: 59 HZ DT: 17.0 MS T-INC:10.0 MS FFT: 256 WIND:HANN
HI-FILT: OFF LO:-40 DB HI: -6 DB AMPL:LOG INT:MED

Figure 4. Frequency spectragram of a discrete call (N4) produced by traveling A pod in the presence of engine noise caused by a variety of purse seiners and whale watching vessels. Sample was recorded at 1141 hours on August 20, 1990. Relative amplitude of engine noise is 3.0V.



DF: 69 HZ DT: 14.6 MS T-INC: 3.2 MS FFT: 256 WIND:HANN
HI-FILT: OFF LO:-40 DB HI: -8 DB AMPL:LOG INT:MED

Figure 5. Frequency histogram relating occurrences of observed behaviors separated by the amplitude catagories in which they occured (n=56).



20
10
0
Observations
Travel
Rest
Forage
0-.49
.5-.99
1-1.49
1.5-1.99
2-2.49
2.5-2.99
Relative Amplitude (V)

Figure 6. Regression: Standard Call Rate [number of discrete calls/whale over time (0.5-1.0 minutes)] versus the relative amplitude (volts) of underwater noise levels (n=463). The regression utilizes all samples taken over all behaviors and includes whales from the following pods: A1, A5, B, C, D, G1, H, I2, R1.

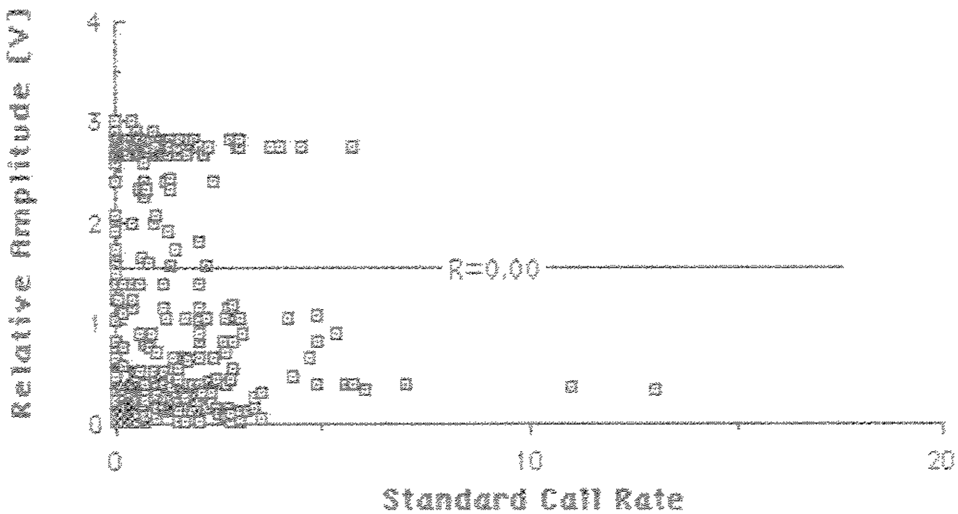
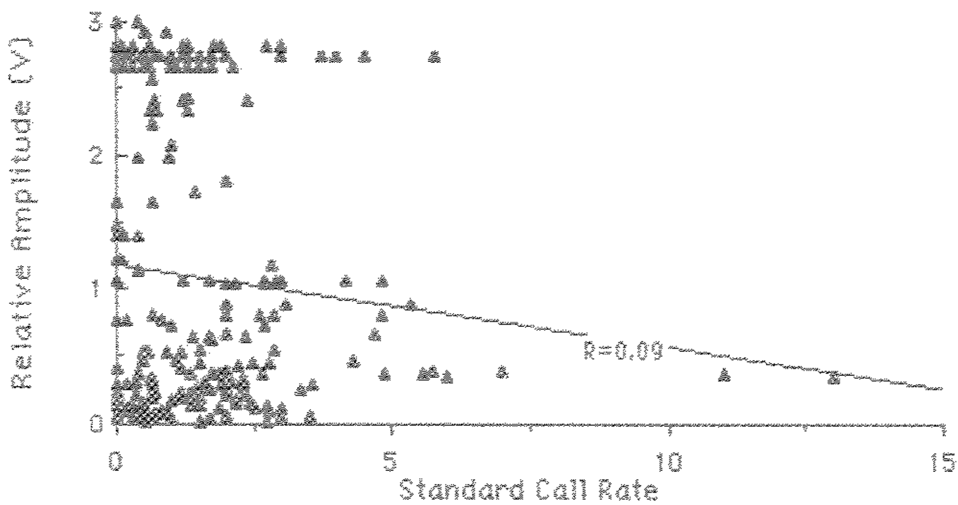
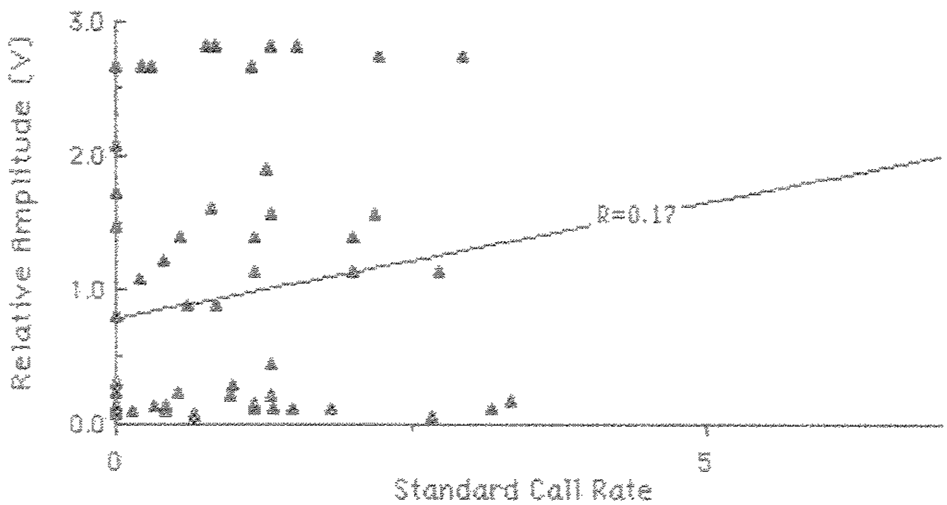

Relative Amplitude [V]
4
3
2
1
0
R=0.00
0
10
20
Standard Call Rate

Figure 7. Travel Regression. Standard Call Rate [number of discrete calls/whale over time (0.5-1.0 minutes)] versus the relative amplitude (volts) of underwater noise levels during traveling behavior (n=250). The regression includes whales from the following pods: A1, A4, A5, B, C, D, G1, H, I2, R1.



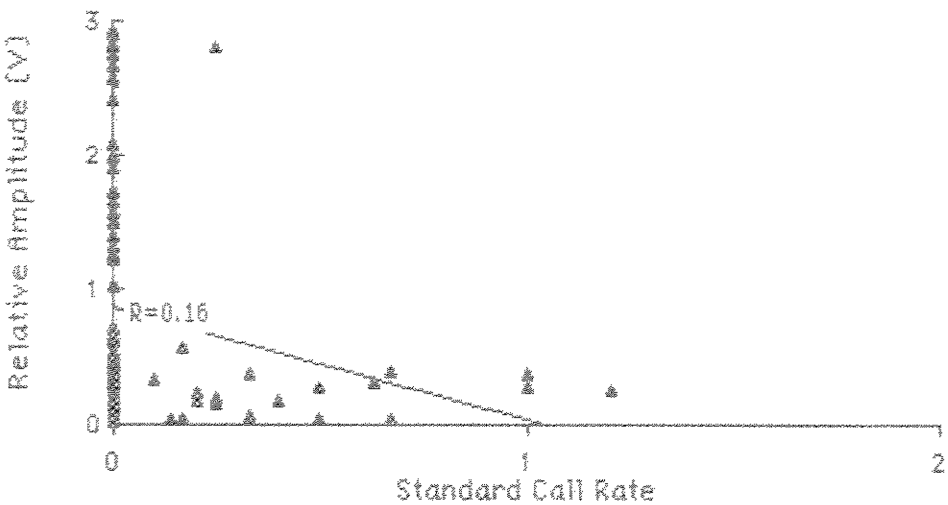
Relative Amplitude (V)
3
2
1
0
R=0.09
0
5
10
15
Standard Call Rate

Figure 8. Forage Regression. Standard Call Rate [number of discrete calls/whale over time (0.5-1.0 minutes)] versus the relative amplitude (volts) of underwater noise levels during foraging behavior (n=63). The regression includes whales from the following pods: A1, A5, C, D.



3.0
2.0
1.0
0.0
Relative Amplitude (V)
R=0.17
0
5
Standard Call Rate

Figure 9. Rest Regression. Standard Call Rate [number of discrete calls/whale over a short period of time (0.5-1.0 minutes)] versus the relative amplitude (volts) of underwater noise levels during rest behavior (n=150). The regression includes whales from the following pods: A1, A5, C, D, G1.



Relative Amplitude (V)
Standard Call Rate
R=0.16
0
1
2
3
0
1
2

Figure 10. Travel Regression-A30's. Standard Call Rate [number of discrete calls/whale over a short period of time (0.5-1.0 minutes)] versus the relative amplitude (volts) of underwater noise levels during traveling behavior (n=35). The regression includes only the A30 subpod during travel behavior.

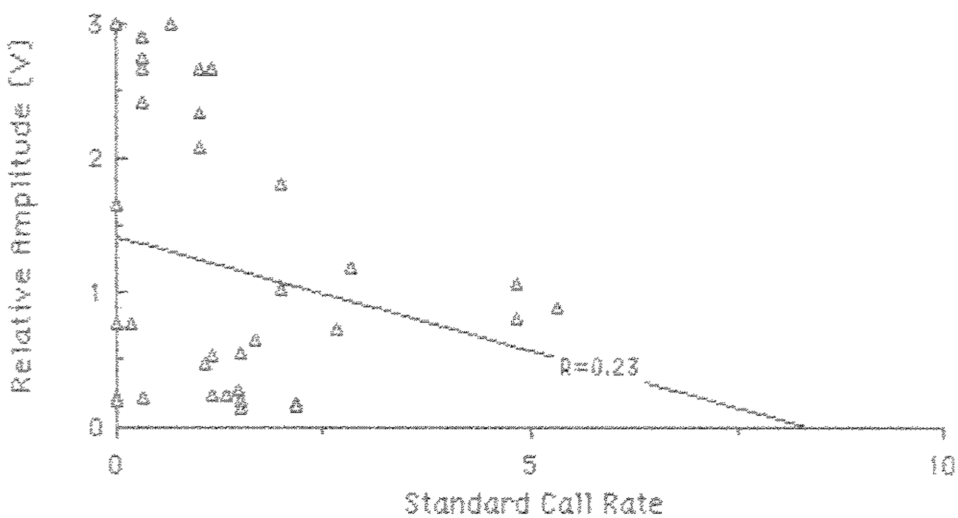
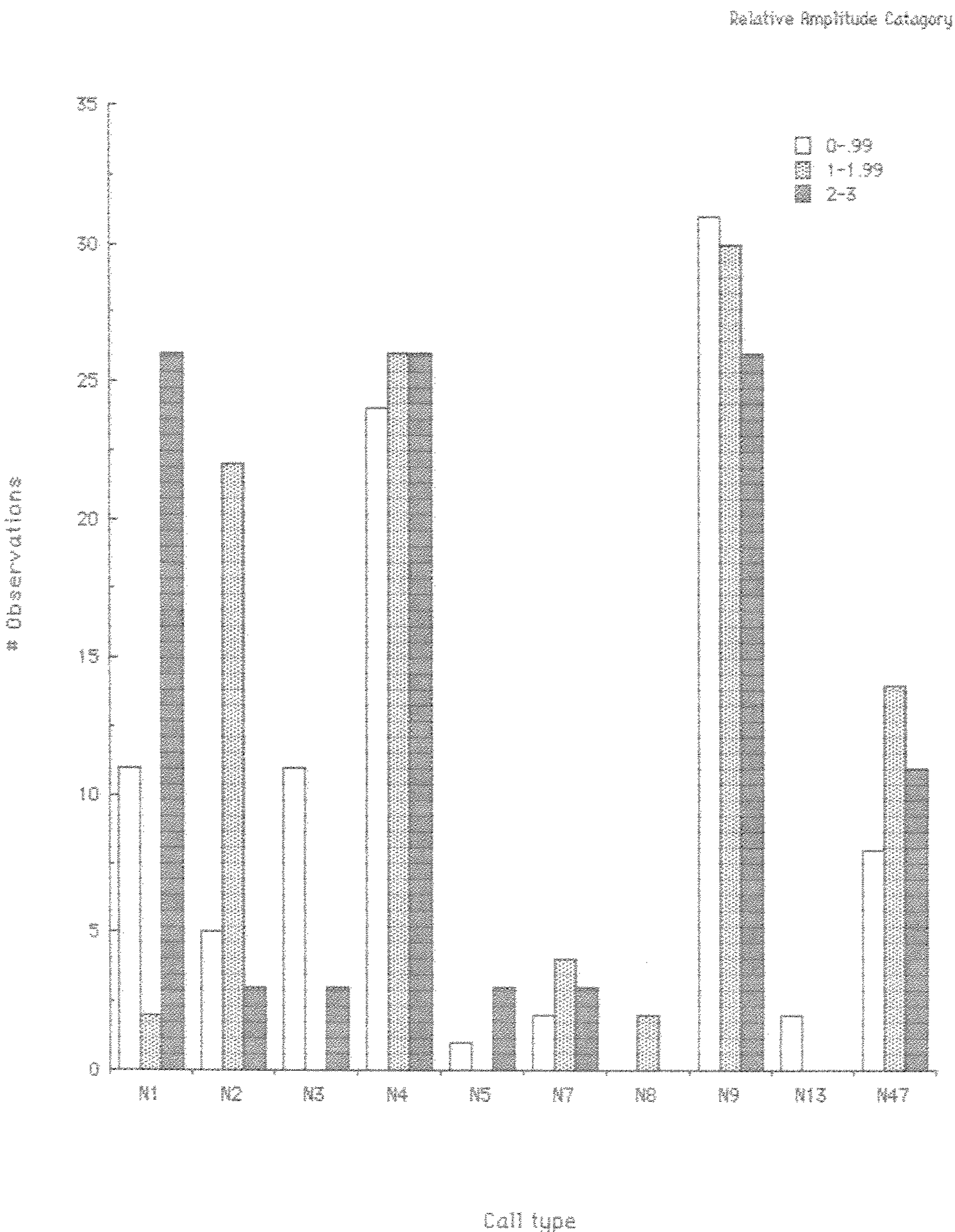

Relative Amplitude [V]
3
2
1
0
0
5
10
Standard Call Rate
R=0.23

Figure 11. Frequency histogram of discrete call types produced by the A30 subpod during travel behavior across differing levels of engine noise (n=272).


Relative Amplitude Catagory
0-.99
1-1.99
2-3
Observations
35
30
25
20
15
10
5
0
N1
N2
N3
N4
N5
N7
N8
N9
N13
N47
Call type