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ACOUSTIC TECHNIQUES OF FISH POPULATION ESTIMATION WITH SPECIAL REFERENCE TO ECHO INTEGRATION

by

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FOREWORD

In March 1968, the University of Washington received one of several Sea Grant Institutional Awards under the National Sea Grant College and Program Act. This program is directed toward development of marine resources and their proper use through rational management policies. For a long time, acoustical devices have been employed to locate exploitable stocks of fish, but, until quite recently, few attempts had been made to quantify signals reflected from fish or other marine organisms, although both the practical fishing industry and management agencies need numerical estimates.

A proposal to develop acoustical means for enumeration of aquatic organisms was submitted and funded in the initial grant to the University of Washington and in the subsequent one. Because of the involved electronic aspects of the problem and applications of interest to fisheries and oceanography alike, an interdisciplinary team was formed with Dr. S. Murphy as team leader and with members from the Division of Marine Resources, the Department of Electrical Engineering, the Department of Oceanography, and the College of Fisheries.

Since salmon fisheries are of great importance on the West Coast of the United States and Canada, it was only natural initially to seek a system that could be used to enumerate both adult and juvenile salmon. The schooling habits of these fish preclude a direct enumeration of individual fish, and the effort was centered on an estimate of the biomass of fish through integration of the reflected echosignals. These, in turn, must be converted into population estimates by a test-fishing program.

This report, written by two graduate students engaged in dissertation research, contains a brief description of the developed integrator and the calibration experiments on stocks of hake and herring in Puget Sound. A subsequent report will deal with population estimates of sockeye salmon in Lake Washington.

Ole A. Mathisen

ACOUSTIC TECHNIQUES OF FISH POPULATION ESTIMATION WITH SPECIAL REFERENCE TO ECHO INTEGRATION

INTRODUCTION

One of the basic problems in fishery management is the lack of reliable means for estimating population size. Present techniques, mainly analysis of catch per unit of effort and tagging experiments, are subject to many assumptions, limitations, and sources of error. Acoustic estimation of population size through the application of ultrasound to fish detection provides a promising solution to the problem.

The recording echo sounder was first used for fish population estimation in the early 1950's (Cushing, 1951). Abundance of fish was estimated by the number of discernible fish echo targets per unit of distance covered. Subsequently, several researchers estimated populations by means of the echo recorder either by counting the number of individual targets or by estimating the size of schools from the size and darkness of the trace (Cushing, 1967). These early studies were subjective in that they required human decision as to whether a mark on the record represented one target or two, or as to the degree of darkness of the trace. Also, often early studies did not take into consideration characteristics of the echo recorder. For example, the type of signal return depends greatly on the frequency and pulse length of the sounder and the amplification or sensitivity of the receiver. In addition, since the volume sampled by the echo sounder increases in proportion to the square of the depth and the intensity of a fish signal decreases in proportion to the fourth power of the depth, the returning signal is greatly modified by depth.

Subjective errors involving human decision can be eliminated by the use of electronic signal-processing equipment. The first electronic counting system was described by Mitson and Wood (1961). This instrument counted targets at three different voltage thresholds. Three types of electronic apparatus for quantifying the returning signals have been described: (1) the relatively simple pulse counter, like that of Mitson and Wood, which counts the number of resolvable targets of more than a minimum threshold level; (2) the pulse length counter described by Carpenter (1967), which analyzes both the number and length of the returning pulses; (3) the echo integrator, first described by Dragesund, Olsen, and Hoff (1965), which measures the total strength (voltage) of echos within a given depth interval and sums these voltages over time.

ACOUSTIC CHARACTERISTICS OF FISH

Two aspects of the acoustic characteristics of fish are of major importance in the evaluation of acoustic techniques of fish population estimation: the relationship between target strength and fish size and the effect of multiple targets and high densities.

Research on the relationship between fish size and echo or target strength has been carried out by several authors, including Jones and Pearce (1958), Hashimoto and Maniwa (1956), Midttun and Hoff (1962), Cushing et al. (1963), Haslett (1962, 1965), Shishkova (1964), and Love (1969). In general, the following relationship is found:

$$\underline{TS} = \underline{a} + \underline{b}(\log \underline{L})$$

where $\underline{TS}$ = the target strength in decibels (a logarithmic scale),
and $\underline{L}$ = the fish length.

There is considerable disagreement on the value of the constant $\underline{b}$; values assigned range from 5 to 60. Haslett contends further that the relationship is different for different size classes, depending on the fish length and the wave length in a complex fashion. Further clarification is needed on this subject.

When fish of the same size and species are distributed evenly and sparsely so that there is no interference between individual fish echos, the returning signals are directly related to the number of fish encountered. At high densities this relationship may be modified by three physical processes: (1) multiple scattering, (2) sound absorption, (3) multiple targets. Shishkova determined the effects of the first two processes; they tend to work in opposite directions, but the overall effect is a decrease in the proportion of the return at very high densities because of absorption of the signal by the fish. The third process, multiple targets, causes the greatest problem in acoustic surveys. When two fish occur in the sampling cone approximately the same distance from the transducer, the echo pulses will arrive at the transducer nearly simultaneously. On an echo recorder, these targets will be merged and may not be resolvable into two targets. According to theory, they can be resolved with a pulse counter when they differ in distance from the transducer by more than one-half the pulse length (Haslett, 1964). Since the speed of sound in water is nearly 1,500 m/sec, a pulse counter on an echo sounder with a 0.5-m/sec pulse length can resolve two targets separated by over 0.375 m. Resolution can be increased by a decrease in the pulse length and a narrowing of the beam. In general, this procedure requires an increase in the frequency. However, some compromise is necessary, since increased frequency means increased attenuation of ultrasound in the water and correspondingly decreased range. Multiple echos are not only difficult to resolve, but the amplitude does not increase in proportion to the number of targets. Truskanov and Scherbino (1966) showed empirically and Lahore (in press) showed theoretically that the amplitude of the return from multiple targets is proportional to the square root of the number of targets. This result is due to cancellation and reinforcement of the wave forms reaching the transducer. When two signals arrive at exactly the same time, the signal is twice that of one, but when they are spaced one-half wave length apart, the two targets cancel each other. Thus on the average the intensity is proportional to the number of targets within the echo, and the signal voltage is proportional to the square root of the number of targets.

THE ECHO INTEGRATOR

The echo integrator measures the summed echo strength of all targets rather than the number of targets.. An echo integrator (described in the Appendix) was developed by Henry W. Lahore under the sponsorship of the Division of Marine Resources and the Fisheries Research Institute of the University of Washington during the summer of 1968 for the purpose of evaluating the potential of integrated echo strength as a tool for fish population estimation. This echo integrator works in conjunction with a Simrad EH2E super sounder with a frequency of 38.2 kH and a minimum pulse length of 0.5 m/sec. The integrator is being used in investigations of populations of Pacific hake (Merluccius productus) and Pacific herring (Clupea harengus palasii) in Puget Sound and juvenile sockeye salmon (Onchorhynchus nerka) in Lake Washington. Integrated echo strength is compared with catch of fish in midwater trawls. The relationship of integration rate to catch of hake per 30,000 m^3 filtered by the midwater trawl is shown in Fig. 1. These hauls were taken at night during February, March, and April, 1969. At this time of year large schools of spawning hake can be located at depths generally greater than 70 m. The integration rate is proportional to the catch at low densities, as indicated by the regression line slope of one on the log-log scale. At high densities the integration becomes proportional to the square root of the catch, indicated by the regression line slope at 0.5. The relationship between integration rate and catch of herring is shown in Fig. 2. These hauls were taken at night during the period October 1968 to January 1969. Contrary to the data for the hake in Fig. 1, the integration rate is proportional to the catch at all densities. This difference can be partially explained by the fact that the herring are near the surface, generally less than 20 m, where the volume of the echo sounder cone is small. Multiple targets are not probable at these densities. Two other possible behavior patterns may have contributed to this result also: the ability of the herring to avoid the midwater trawl may increase with density, and the packing density of schools of herring may remain similar even though the overall density varies.

COMPARISON OF ACOUSTIC TECHNIQUES

In a simple system containing mainly a single species of a uniform size and with an insignificant number of multiple targets either because of low density or shallow depth, all three electronic survey techniques can result in a good correlation between electronic output and net catch. Further, with adequate calibration equipment the outputs can be calibrated to absolute numbers, without dependence on assumptions of net efficiency. However, because of the fact that the integrator examines the total returning echo strength rather than the number of targets, it has a major advantage in surveying. The echo sounder beam is approximately cone-shaped; therefore, the volume increases with depth, and the number of targets increases for any fixed density. Thus there is a built-in bias in the output of any counter. To reduce this bias, one must sample only limited depth intervals. When a survey is concerned with a large depth interval, it is advisable to use more than one counter to increase the coverage. The echo integrator can be used, with appropriate adjustment, to survey over any depth interval within the range of detection of the echo sounder, since for any given density of fish the returning signal voltage decreases

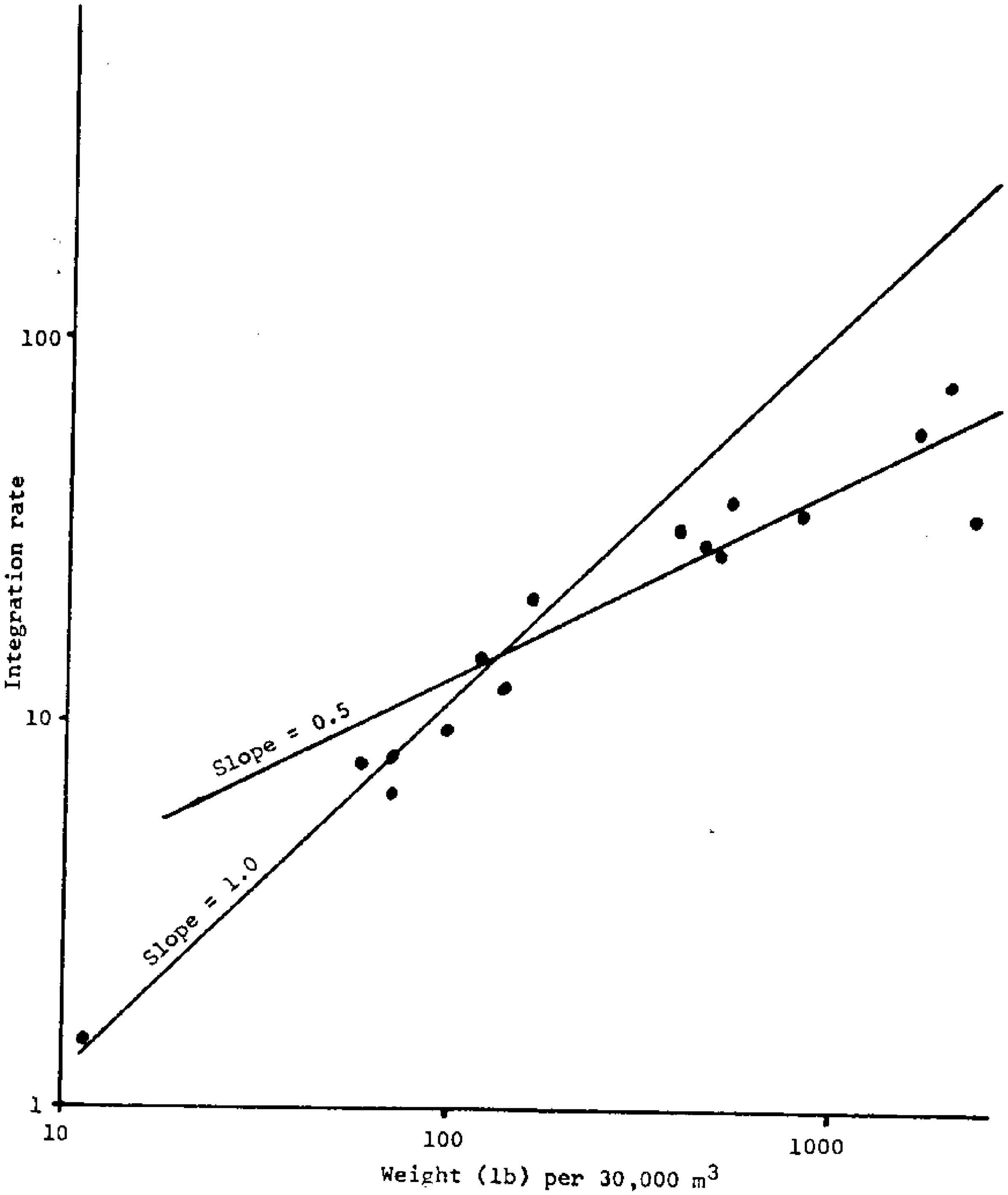

FIG. 1. Relationship between integration rate and density of hake in Puget Sound, February, March, and April, 1969. (Catches taken by midwater trawl and all trawling done by night.)

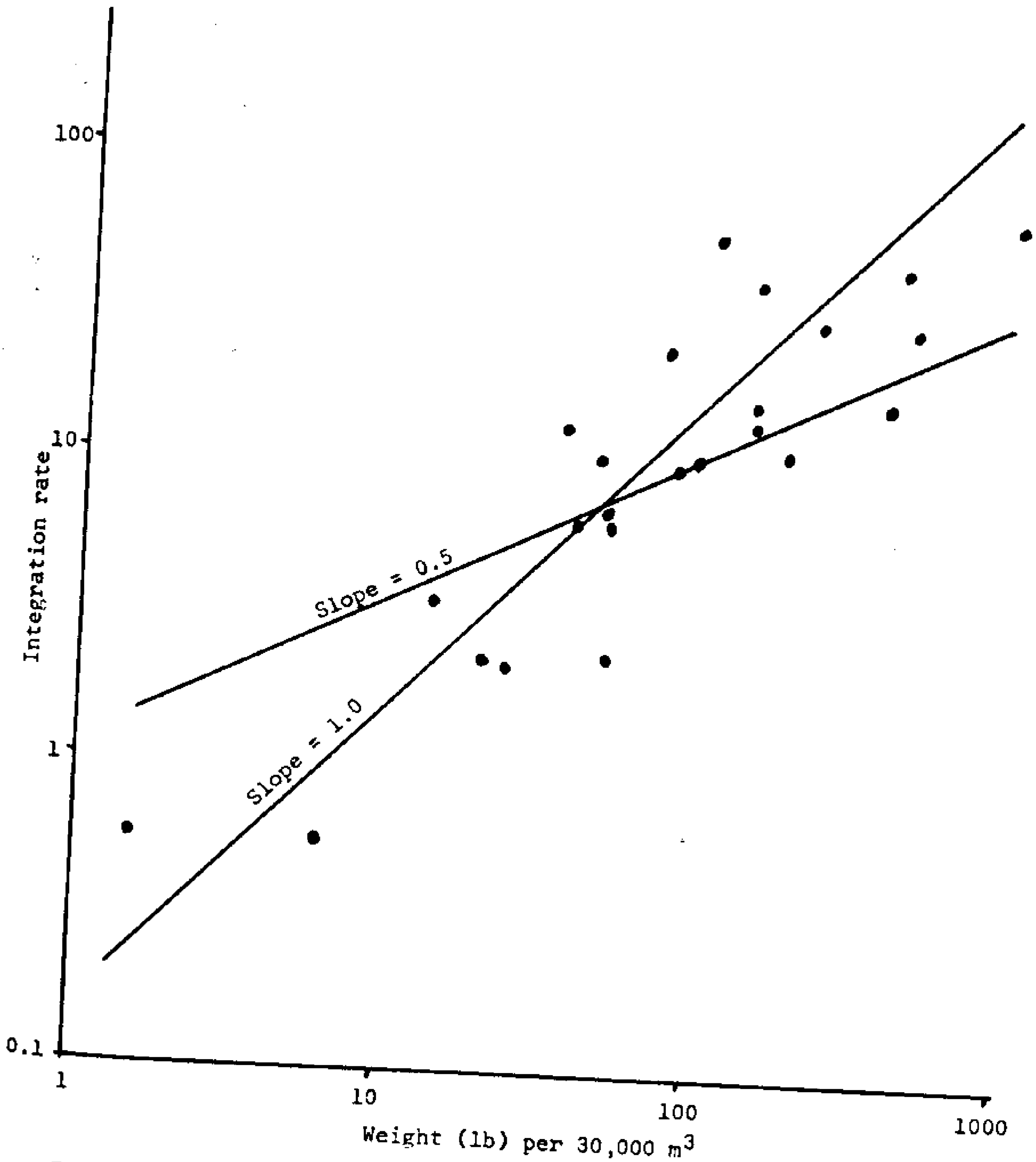

FIG. 2. Relationship between integration rate and density of herring in Puget Sound, October, 1968-January, 1969. (Catches taken by midwater trawl and all trawling done by night.)

in proportion to the depth. When the echo sounder or integrator is equipped with the appropriate time-varied-gain, the signal voltage is compensated for the decrease with depth. This technique was used successfully in a survey of the Lake Washington sockeye salmon in February, 1969 (Thorne and Woodey, unpublished report).

When high densities or deep depths are characteristic of the survey area, problems are encountered because of multiple targets, and the population is underestimated. Take as an example a situation where four fish are tightly schooled within a depth interval less than one-half the pulse length of an echo sounder. Both the pulse counter and the pulse length counter would count only a single fish. On the average, the echo integrator would count two fish, according to the square-root relationship of Truskanov and Scherbino, and it might even be possible to square the pulse, and thus count four fish. Such a squaring function has not been experimented with yet, but would be a valid procedure in a system where all individual targets are of similar size if, as suggested by the work of Truskanov and Scherbino, the voltage is proportional to the square root of the number over most densities.

In the case where multiple targets are significant, it is no longer possible to integrate over a large depth interval without bias, since the frequency of multiple targets will increase with depth because of the increased sampling volume. It is then desirable to use more than one integrator for surveying large depth intervals, although the degree of bias is still much less than with a counting system.

Major difficulties are encountered with acoustic survey techniques in a situation where the species and size distribution are complex. It is still possible to count the number of targets with counting systems, providing useful data when species composition is known from net hauls. Where two distinct size groups occur, it may be possible to count at two different amplitude intervals, provided that the presence of multiple targets does not obscure the difference in individual target strengths. Similar difficulties are encountered with the echo integrator. When the species composition remains relatively constant, integration provides useful results. At present, little is known of the relationship between echo strength and size. If the relationship is a function of weight or square of length or length alone, the integrator will give an estimation of the sum of these parameters. This result will still give little information on the contribution from each species, although this contribution can be estimated from net hauls just as with counting techniques. A further source of difficulty may exist for the integrator if, as Haslett suggests, the relationship between fish size and target strength does not remain constant over a large size range.

SUMMARY AND CONCLUSIONS

Acoustic techniques appear to be a promising means of direct population estimation for pelagic and semipelagic fishes. In particular, the echo integrator has several of the desirable characteristics in a survey tool. The Washington State Department of Fisheries is utilizing it at present to survey the juvenile sockeye salmon population in Lake Washington and the hake population in Puget Sound. The echo integrator has several advantages over counting systems: it can survey over a wider depth interval with a single channel output; it gives a better approximation under conditions where multiple targets are prevalent; and it has the potential for estimating multiple targets in systems where a single size class of fish preponderates. At present the integrator is of limited value in complex systems where a large range of sizes is encountered since little is known of the relationship between signal strength and fish size. All present acoustic techniques are inadequate for surveying systems where both frequent multiple targets and diverse size and species distributions are found.

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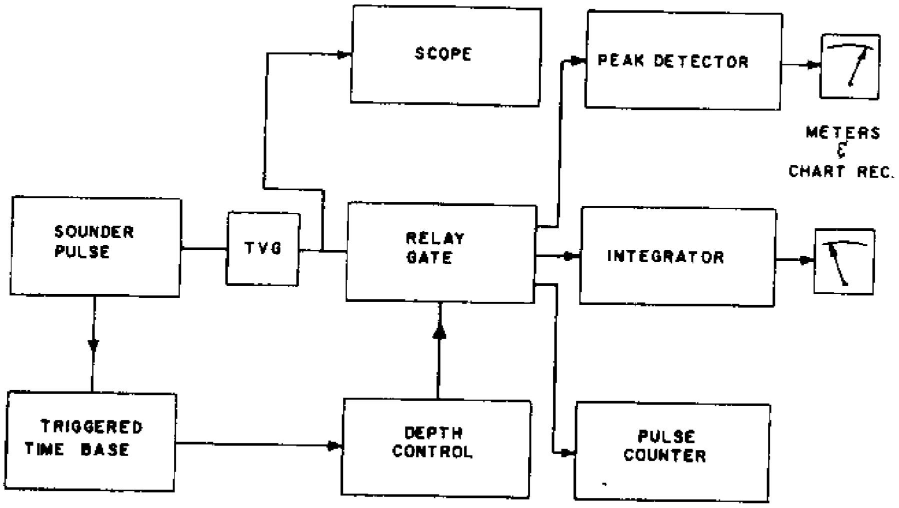
APPENDIX

DESCRIPTION OF ECHO INTEGRATOR

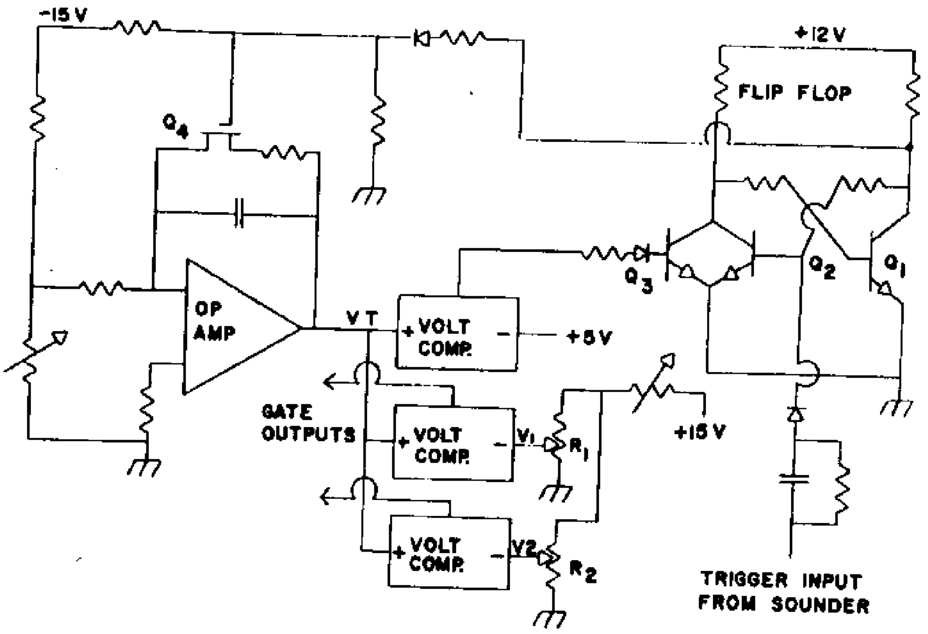
This appendix contains an outline of the design of the echo integrator that was developed by the author. The details of the circuit design will be published in a technical report from the Division of Marine Resources of the University of Washington.

An electronic integrator is a device that has at its output terminal the integral over time of the voltage x time that has been applied to its input, that is, it sums up the echo amplitude times duration. A block diagram of the echo integration system is shown in Fig. 1. The time base of the system is triggered by a pulse from the echo sounder. Using this time base, the circuit turns on the relay for the depth interval to which it has been set. The signal from the sounder receiver goes into the time-varied-gain circuit, is rectified, and put through the relay contacts to the integrator, peak detector, and pulse counter. The peak detector indicates the maximum amplitude of the signal in the gated time interval. This serves to adjust the input to a good voltage range and to provide a record of echo density. The pulse counter indicates the number of pulses in the gated interval that have been over a certain amplitude. For low densities this results in a count of the number of fish that have been in the depth interval examined.



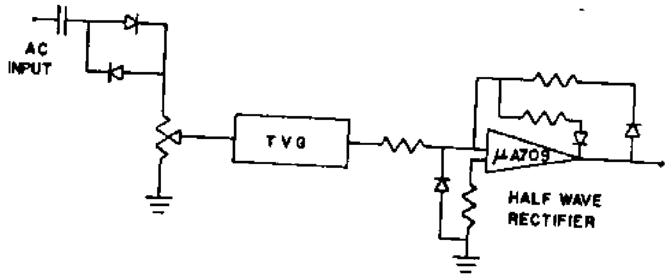
APPENDIX FIG. 1. Block diagram of echo integrator system.

The time base and depth control circuitry is shown in Fig. 2. When a trigger signal is received from the echo sounder, the flip flop changes,



APPENDIX FIG. 2. Time base and depth control circuitry.

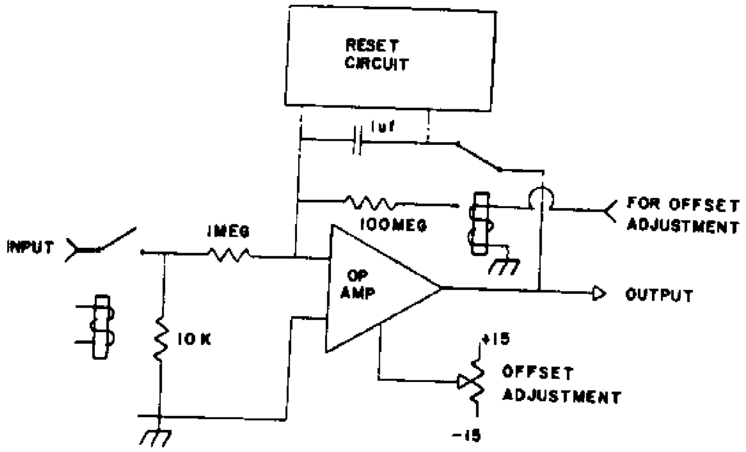
turning transistors Q_1 and Q_4 off. This starts a voltage ramp (V_t). The voltage comparators compare V_t to the voltages present on R_1 and R_2. R_1 and R_2 are ten-turn potentiometers with three-figure dials reading full scale to either 100 or 300 m. The two lower voltage comparators control the gate circuitry, which drives the relay at the input of the integrator. The upper voltage comparator resets the flip flop at a depth of about 400 m. The voltage comparators used are Fairchild integrated circuit μA710.



APPENDIX FIG. 3. Input circuitry.

The input circuitry is shown in Fig. 3. The job of the input circuitry is to prepare a good depth-corrected DC signal to be integrated. The AC input indicated on the figure comes from the IF part of the echosounder receiver section. The diodes serve to attenuate low noise. They should be positioned after the attenuator, but the signal level there is too low in this design. The TVG is 20 log R and lasts for 150 m. The operational amplifier serves as an amplifier and half-wave rectifier with a very low diode offset voltage.

An operational amplifier with capacitor feedback is used as the electronic integrator in this system (Fig. 4). This is the only way of making an accurate voltage integrator that can be used over a large range of input and output voltages. The relay at the input is turned on at every sounding for the depth interval set on the depth potentiometers. Thus echos from only the depth interval of interest are integrated. The reset circuit, shown in block form, discharges the one µf integrator capacitor when its voltage is near the output voltage capacity of the operational amplifier. Thus the integration proceeds without data being lost. The output goes to a meter on the echo integrator panel and to a chart recorder. The operational amplifier used in this system was Analog Device Inc. #211. Another echo integrator we are presently building uses Fairchild µA727 and µA741 combination.



APPENDIX FIG. 4. Electronic integrator circuit.