DIGITAL HYDROACOUSTIC DATA-PROCESSING SYSTEM AND ITS APPLICATION TO PACIFIC HAKE STOCK ASSESSMENT IN PORT SUSAN, WASHINGTON[1]

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ABSTRACT

A digital hydroacoustic data-processing system was developed at the University of Washington utilizing the general-purpose computer PDP/8L. The system, which functions as a 20-channel squared voltage integrator, was applied to the annual assessment of the spawning stock of Pacific hake, *Merluccius productus*, in Port Susan, Wash. Four surveys were conducted between 14 and 16 March 1971. The population estimates based on calibration by net hauls ranged from 15.9 to 18.8 million lb. An estimate of 18.2 million lb was obtained with an analog voltage integrator for one of the surveys. The digital system provided more detailed information on the horizontal and vertical distribution of the fish and resulted in a much smaller variance of the estimated mean fish density than the analog system.

Echo sounders have been used extensively since 1950 as a means of studying the distribution and relative abundance of fish populations, but only during the last decade has the tedious interpretation of echograms begun to be obviated by the development of electronic devices for automated signal processing. These are basically of two types, echo counters (Mitson and Wood, 1961; Carpenter, 1967; Dowd, 1969) and echo integrators (Dragesund and Olsen, 1965). The principles governing the application of acoustics to fish abundance estimation are described in Parrish (1969).

An analog echo integrator was designed and built at the University of Washington (Lahore, 1969) as part of a general study of acoustic methods of resource assessment in the University's Sea Grant Marine Acoustics Program. It was used in investigations of the relationship between integrated echo voltage and fish density (Thorne, 1971) and of the population size of juvenile sockeye salmon, *Oncorhynchus nerka*, in Lake Washington in 1969 (Thorne and Woodey, 1970) and of Pacific hake, *Merluccius productus*, in Port Susan in 1969 and 1970 (Thorne, Reeves, and Millikan, 1971). It became apparent during these investigations that integration with analog echo integrators had several disadvantages, such as instability and limited dynamic range, which could be eliminated by suitable digital circuitry. Consequently, a digital processing system was designed and built around a small general-purpose computer. A preliminary report of the Digital Data-Acquisition and -Processing System (DDAPS) was reported in Moose, Thorne, and Nelson (1971). A detailed description of the system and its initial application to the population assessment of Pacific hake in Port Susan, Puget Sound, Wash., in 1971, is presented here.

MATERIALS AND METHODS

The Digital Data-Acquisition and -Processing System

The DDAPS is constructed for use with the general-purpose computer PDP/8L, 4 K memory, manufactured by Digital Equipment Company. A block diagram is shown in Figure 1. The amplified signals from either one or two echo sounder transducers are envelope detected, low pass filtered, multiplexed (should two sounders be in use), A/D converted into 8-bit binary words, and then digitally squared in a

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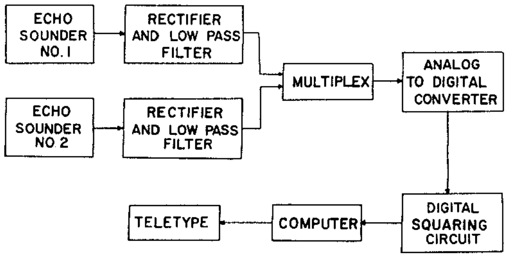

FIGURE 1.—Block diagram of Digital Data-Acquisition and -Processing System (DDAPS).

hardwired 8- × 8-bit multiplier. Squaring results in an output that is proportional to acoustic intensity (Thorne, 1971). Conversion to digital form before squaring eliminates the problems with dynamic range associated with analog voltage squared integrators. The 12 most significant bits of the square are retained and transmitted to the PDP/8L central processing section.

The processing section adds the squared data words to the appropriate integrator. Ten contiguous depth intervals are provided for each sounder, so that a maximum of 20 integrations may be operating simultaneously.

Overall timing for the system comes from the echo sounders. An initiation pulse signals the computer to begin data processing. A bottom signal indicates to the computer that the sea floor has been reached. Thus the bottom can be tracked and integration terminated a short distance above it. The magnitude of this distance is an input value to the computer and generally depends on the steepness of the slopes. Typical values are 2 to 3 m. If occasional bottom echos are too weak to activate the bottom indicator signal, the computer automatically terminates integration just above the last known bottom depth. The bottom can also be tracked manually under circumstances, such as extremely steep slopes, where the bottom signal is consistently too weak to be followed automatically.

The program keeps count of the transmitted signals, and when the count reaches the input value for "number of pings," processing terminates. Alternately, the operator may terminate processing by setting a sense switch.

In the output section, the integrator value is teletyped for each depth interval for each sounder. Using input constants relating integration to fish density, the program then calculates the fish density from the integrator values, automatically correcting for depth. An example of the output is given in Figure 2. The mathematical relationship between integration and fish density is detailed in Thorne (1970), Moose and Ehrenberg (1971), and Moose, Ehrenberg, and Green (1971). The constant relating fish density to integration from any echo sounder can be calculated when the target strength of the fish and absolute calibration of the sounder and transducer are known. Alternately, the constant may be determined indirectly by calibration of the integration against other measures of fish density, such as net hauls or echo counts (Thorne, 1971, 1972).

The hardware of the DDAPS, with the exception of the teletype, is contained in a 4-foot-high, 19-inch relay rack. The special circuitry is packaged on 4- × 6-inch, plug-in, wire-wrapped cards. All digital circuitry is integrated circuit, TTL logic. The system is highly portable and is easily moved from laboratory to ship in several hours. It is intended for processing data aboard ship in real time, and in

Number of Pings

P = 145

Upper limit of Depth interval (m)	Integration	Density (fish/m^3)	Number of Samples
20	4334	+0.650E-03	78445
60	26948	+0.885E-02	58870
90	32777	+0.174E-01	44940

FIGURE 2.—Sample DDAPS output for one echosounder and three depth intervals.

the laboratory from either digital or analog magnetic tape.

Survey Area and Methods

Port Susan (Figure 3) is exceptionally well suited to hydroacoustic assessment studies. It is a long, narrow basin with steep sides and relatively uniform depth (between 100 and 120 m). Each winter large concentrations of Pacific hake enter Port Susan to spawn. They occupy depth strata below 50 m and make up over 90% of the biomass in these depths. An industrial fishery was initiated in Puget Sound in 1965. Annual landings have ranged from 6.3 to 10.6 million lb, over 80% of which have come from Port Susan (Millikan, 1970). Acoustical censusing of Pacific hake in Port Susan was undertaken in 1969 and 1970 by the use of analog echo integrators (Thorne et al., 1971).

During 13 to 16 March 1971, 4 surveys and 21 net hauls were made for evaluation of the DDAPS. Each survey consisted of nine oblique transects spaced evenly throughout Port Susan (Figure 3). The net hauls and three of the surveys were conducted aboard the research vessel *John N. Cobb*, operated by the Northwest Fisheries Center, National Marine Fisheries Service (NMFS), NOAA, Seattle. The fourth survey was conducted with a 23-foot inboard-outboard cruiser, *Research 1*, of the Washington State Department of Fisheries. Both vessels

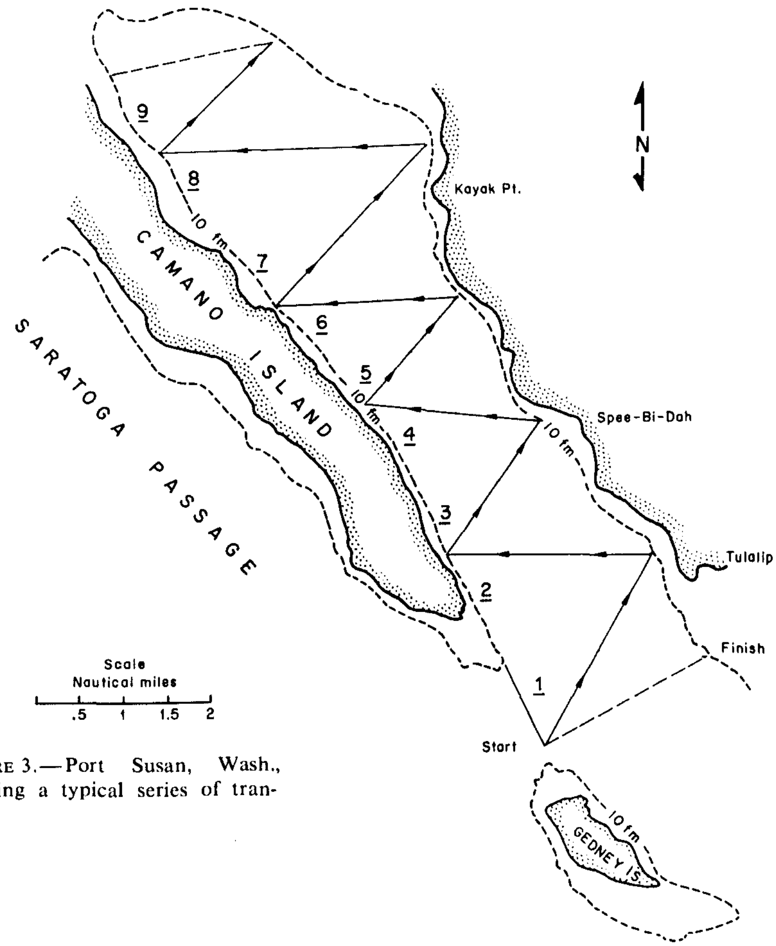

FIGURE 3.—Port Susan, Wash., showing a typical series of transects.

were equipped with Ross 200A Fineline echo sounders,[3] with a frequency of 105 kHz and a pulse length of 0.6 msec. The transducers produced circular beams approximately 8° full beam angles to the -6 dB points. The echo sounding data were heterodyned to 6 kHz and recorded on analog magnetic tape for later analysis. Details of the data-acquisition system are given in Thorne, Nunnallee, and Green (1972). Net hauls were made with the pelagic trawl described in Thorne (1971). The net filtered approximately 30,000 m^3 in a 10-min tow.

Data Analysis and Calibration

The echo data collected on magnetic tape during both the surveys and the net hauls were analyzed with the DDAPS. Integrated squared voltages were determined in 10-m depth strata from 60 m to 120 m. The relationship between integration and fish density was computed from the net catches as in previous surveys (Thorne et al., 1971). Integrated squared voltages were determined over the duration (10 min) of the net hauls, and fish densities were found from the net catches with an assumption of 100% net efficiency and regressed against the integrations from the corresponding 10-m depth strata including the mean depths of the net. The depths of the net were determined by the use of an electrical telemetry system (Lusz, 1967). Then this relationship was used to determine fish densities from the integrations along transects. During analysis of the data collected on transects, integrated voltages and corresponding densities were usually put out every one-third of each transect.

Data from one of the surveys (14 March) and the net hauls were also analyzed with an analog voltage integrator for comparison. The integrator used was the unsquared voltage integrator described by Thorne (1971). Integrated voltages were determined over 10-m intervals centered on the mean depths of the net. The relationship between integrated voltage and fish density was computed as above. Integrated voltages and corresponding densities were found over the complete duration of each transect in each of the depth intervals 60-75 m, 75-90 m, and 90 m to the bottom.

RESULTS

Relation Between Integrated Voltage and Net Catch

Net catches of Pacific hake and corresponding integrated voltages from the DDAPS are shown in Figure 4. The corresponding data from the analog echo integrator are shown in Figure 5. The integrated voltages from both systems are definitely linearly related to respective fish density as represented by catch. A linear regression model was fitted to the data from each integrator. The model was

$$D = bI$$

where D is catch in pounds of hake per 30,000 m^3, and I is the integrated voltage.

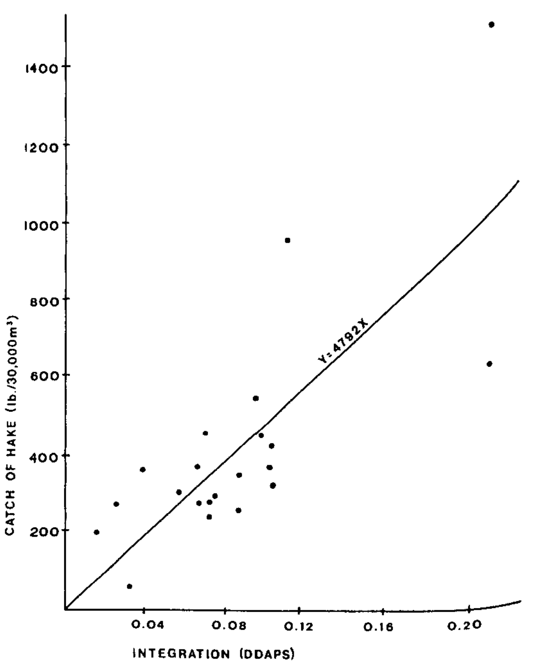

FIGURE 4.—Relation between catch of Pacific hake and integration output from DDAPS.

[3] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

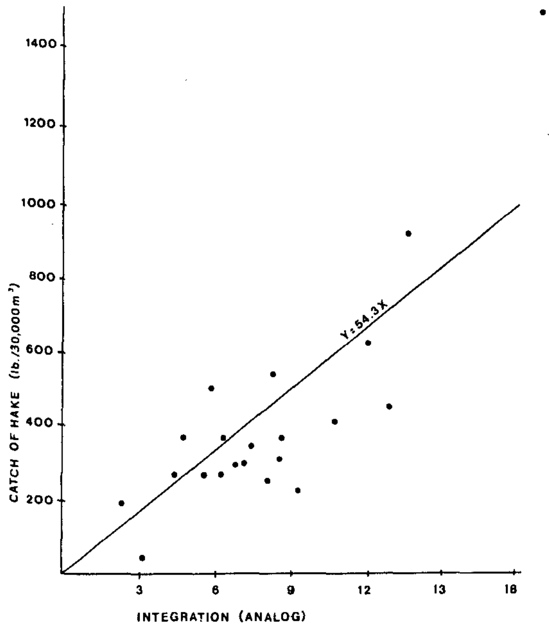

FIGURE 5.—Relation between catch of Pacific hake and integrated voltage from analog echo integrator.

The relative error of the beta coefficient was 8.0% for the analog integration data and 9.4% for the DDAPS, where relative error is defined as the ratio of the standard deviation of beta to beta expressed as a percentage.

Population Estimate

The number of integrated voltages and corresponding density observations from the DDAPS varied from 125 to 145 per survey. A weighted mean density of Pacific hake was determined for each survey and for all surveys combined. Each observation was weighted in proportion to the associated number of samples in the DDAPS output (Figure 2), which depended on the number of pings and the depth interval (10 m or less, depending on depth of bottom). The population of Pacific hake in Port Susan was estimated by multiplication of the estimated mean density of Pacific hake by the volume of water covered by the various surveys, expressed as the surface area at the 60-m contour (50×10^6 m²) times the average depth interval. The average depth interval was obtained directly from the number of samples. Since the DDAPS reads the integrated voltages at a rate of 10,000 per second, or each 0.073 m of depth, the average depth surveyed during a transect series was the average number of samples per ping times 0.073 m. The weighted mean densities, associated variances, volumes, and estimated total biomasses for the four series and for all series combined are given in Table 1. The population estimates for the four series ranged from 15.9 to 18.8×10^6 lb. These estimates are higher than the preliminary results reported in Moose, Thorne, and Nelson (1971) because of the greater area involved (50×10^6 m²).

A weighted mean density was also determined for the survey analyzed with the analog echo integrator. The densities along each transect were weighted by the duration of the transect. Since depth was not determined directly, the volume was assumed to be the same as that determined with the DDAPS analysis of the same survey. The results of the analysis are also given in Table 1. The population estimate was 18.2×10^6 lb.

TABLE 1.—Results of data analysis for various transect series.

Series		Mean density (lb/10⁴ m³)	Variance of mean	Volume (10⁹ m³)	Population estimate (10⁶ lb)	Number of observations
DDAPS:						
John N. Cobb,	14 March	81	13.5	1.96	15.9	125
	16 March	98	13.3	1.76	17.2	142
	16 March	105	15.0	1.75	18.4	137
Research I,	16 March	83	18.8	2.26	18.8	145
All series grouped		93	3.96	1.90	17.7	549
Analog:						
John N. Cobb,	14 March	93	41.2	1.96	18.2	26

DISCUSSION

A major advantage of the digital processing system is the ability to estimate fish densities in a number of depth strata simultaneously. This ability allows detailed examination of the variation of density with depth. During the 1971 surveys in Port Susan the Pacific hake were uniformly distributed over both depths and transects, so that it was possible to consider all observations as estimates of the mean fish density. A slightly different distribution was found during the 1970 acoustic surveys, when two density strata were identified (Thorne et al., 1971). During the acoustic surveys in Port Susan in 1969 and 1970, integration was done directly off the sounders and a single output was obtained, including the entire depth range of interest. Thus only one estimate of density was obtained for each transect, and only 9 observations were made over a standard set of nine transects; whereas 26 observations were obtained from the 1971 survey processed with the analog integrator and 125-145 observations were taken with the DDAPS from 10-m depth strata and three outputs per transect. The increased number of outputs greatly decreased the variance of the estimated mean density. For example, Thorne et al. (1971) calculated that 36 transects (18 per stratum) were required to reach a precision of $\pm 15\%$ in 1970, neglecting variance in the calibration relationship. This level was reached in nine transects processed in three depth intervals with the analog integrator from magnetic tape in 1971, whereas precisions of about $\pm 8\%$ were shown for nine transects processed by the DDAPS, and a precision less than 5% for the combined four series (549 observations).

The estimates of total population from the four series processed with the DDAPS varied even less than the estimates of mean density because of an apparent inverse relationship between density and average bottom depth. It is possible that shallower areas had slightly higher fish densities. It is interesting to note that the range in estimated fish density for the four series was not much greater than the range in estimated average depth of Port Susan (mean 98 m, range 95-105 m).

A good linear relationship was obtained between catch and integrated voltage for both the digital and analog systems in 1971. The relative error of the beta coefficient for the relationship between integration and catch obtained in 1970 was quite large, 29% compared to less than 10% for both systems in 1971. Part of the variability in the 1970 results probably was associated with instability in the analog voltage-squared integrator.

The highly linear relationship between catch and integration from the 1971 analog voltage integrator was somewhat surprising. Since the integrated voltages were unsquared, the relationship should have deviated from linearity at higher densities (Thorne, 1971). However, densities were relatively low compared to the resolution of the system. The pulse resolution volume at the mean haul depth (80 m) was about 40 m^3, if an $8°$ cone and 0.6 msec pulse length are assumed. Thus a catch of about 525 lb (750 fish) would be equivalent to an average density of one fish per pulse resolution volume. Only four catches were greater than 525 lb. There is some indication that the highest two observations may be deviating from linearity. The ratio of fish density to integrated voltage associated with multiple targets would be greater and would tend to increase the magnitude of the beta coefficient over that expected from all single targets. This effect may account for the greater population estimate derived from the survey processed with the analog echo integrator.

Estimates of density of fish from an echo integrator are dependent upon determination of the individual fish's mean target strength (Moose, Ehrenberg, and Green, 1971). In acoustic studies of Pacific hake populations in Port Susan since 1969, the mean target strength has been determined indirectly from comparison of integrated voltage with net catches, on the assumption of 100% net efficiency. The procedure provides a valuable relative index for annual comparisons, but suffers from a large variability associated with the net catch and from possible bias in the assumptions concerning net efficiency. A relative error of 9.4% was associated with the calibration relationship between the catches from the 21 net hauls and the integrated voltages from the DDAPS in 1971. The theoretical variance of the relationship should be considerably less according to the model of Moose and Ehrenberg (1971). The greater part of the observed variability is undoubtedly associated with the catching process. Further development and understanding of methods of target strength measurement are needed so that this variability may be reduced and absolute densities can be directly estimated.

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