Attachment 10

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HYDROACOUSTIC SURVEYS OF THE BERING SEA WALLEYE POLLOCK.

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The walleye pollock, *Theragra chalcogramma,* resource of the continental shelf of the Bering and Okhotsk Sea, supports one of the largest in the world fisheries activities. The species is semi-pelagic and is generally found in pelagic and demersal areas over depths of 25 – 400 m. Some groups of scientists from the USA, Russia, Japan engaged in study of the species *(0hshima et a/, 1996; Traynor, 1995).*

The demersal component of the stock is usually assessed during bottom trawl surveys while pelagic component is studied using acoustic surveys *(Karp and Wallers, 1994)*. It was stated by numerous surveys that usually demersal orientation is more common for older fish, and younger fish are more distributed in midwater. Simultaneously conducted bottom trawl and acoustic surveys could give new data to estimate the stock and to compare different ages vertical distribution.

The surveys were conducted simultaneously in the same area of the west part of Bering Sea near cape Navarin from October 25 to November 5, 2001. Acoustic data were collected in the whole water column using EY500 Simrad echosounder on the board of Japanese trawler KAYE-MARU №28". The trackline consisted of 487 nautical miles *(Fig.1).*

The following a specialized complex of the equipment and the software was used for the echo survey:

- echo sounder EY500 Simrad (38 kHz) with single beam antenna in the towed body;
- PC, used as the block of management and monitor of echo sounder;
- GPS receiver of firm Trimble Navigation (USA), connected to the computer of the echo sounder and automatically determining coordinates of a vessel, which are registered together with acoustic data;
- magneto-optical drive Fujitsu FMO-1300WS2 for recording echo signals from the computer, which was used as the store of the information;
- echo processing system EP500 Simrad for reproducing and processing of the recorded echo signals.
- colour printer DeskJet HP850C (Hewlett Packard).

Complex allows to automate completely the collection of data during echo survey, providing record of primary data *(as echo signal from an output of echo* *sounder)* for their subsequent storage and processing. Other important peculiarity of a complex is an automatic determination of coordinates of a vessel with rather high precision of GPS system, registration of echo signals and coordinates simultaneously. It allows to calculate plots of distribution of measured parameters, to locate significant interesting records.

Nowadays advanced direction in hydroacoustics are methods and equipment of a quantitative estimation of fish schoolings. Created methods *(Manual of hydroacoustic surveying //VNIRO, Moscow, pp.124, 1984)* are well fulfilled and are widely used for biomass estimation of fish schooling and its distribution at realization echo survey in process of fishery researches with the use of echo sounders and echo integrators.

The method of realization of hydroacoustic surveys includes the following standard stages:

- installation of the equipment on a vessel and checking its functioning;
- calibration of the equipment with the use of standard copper sphere;
- choice of transects and parameters of echo survey (speed of a vessel, length of transect lines, place of control trawling, elementary sampling distance unit (ESDU) and etc.);
- choice of working parameters of the equipment during survey;
- directly registration and record of echo sign;
- data processing of survey, plotting of the echo integration results, estimation of the biomass with a confidence intervals.

The antenna of echo sounders was towed from the left board on a course of a vessel on depth about 2 m, in order to exclude influence of reflections of a echo sounder signals from the frame of a vessel and superficial of sound-scattering layers (air bubbles). Proceeding from the methodical recommendations of operation of the echo sounders and design peculiarities of a vessel, the speed of a movement was chosen 5.5 - 6 knots.

The choice of a transects was determined in view of results of the previous surveys, and also with necessity of more detailed surveying of chosen region. Transects of hydroacoustic survey crossed depths about 200 meters. The preliminary tests of echo sounder EY500 have show that the level of a signal-to-noise-ratio at duration of a pulse 1 msec *(Medium)* on such depthes has appeared unsufficient. Therefore duration of a pulse 3 msec *(Long)* with a narrow band was chosen. The record of echo signals was conducted during the day-and-night time with breaks, necessary for conduction control trawls.

Control trawls were carried out in places with high density of fish schooling and at change of character of their registration, where it was possible.

Biomass calculation *W* was computed according to a «Manual of hydroacoustic surveying» *(VNIRO)* and instruction for use of echo processing system EP-500.

The technology of processing of acoustic data based on a principle of detailed stratification of region with the account length category of pollock stocks and another species. In a basis of such approach lay the following parcels:

- the acoustic image of a schooling rather adequately displays spatial distribution and behaviour of objects on a certain part of a way in a certain interval of time of days;
- the change of a kind of the acoustic image serves the indicator of change of behaviour and, probably, age-length characteristics of a fish and is subject to check control trawling;
- in case there is record of object in various depth horizons, control trawlings are carried out for separate identification of each type of schooling.
- in accordance with receipt acoustic datas during survey the empirical analysis of echo signals, taking into account character of behaviour of object, type of distribution of target strength *(TS, dB)*, results control trawling, experience of previous work in the certain region came true. In result of the conducted analysis of an acoustic situation parts of a way on transects of acoustic survey, schoolings appropriate to the characteristic acoustic description with certain length category, confirmed by results control trawlings on certain schooling. Were allocated, in the subsequent such part of a way and length-frequent line appropriate to a schooling were used for biomass calculation of an identified schooling on the given piece of acoustic transect.

Calculating of signals is made on echo processing system EP500 Simrad by a echo-integration method. The values received as a result of surface back scattering strength *Sa* $(m^2/mile^2)$ were converted in area density values of fishes one-size group ρ_i $(ton/mile^2)$ using the following general formula:

$$\rho_i = S_a \cdot \frac{f_i}{\sum_1^n f_i \cdot \sigma_i} \cdot \omega_i \cdot 10^{-6};$$

where: ω_i - mean weight of *i -size* group of fish *(g),*

σ_i - mean value of acoustic back-scattering cross section of *i-size* group of fish (m^2).

f_i - share of *i-size* group of fishes in control trawl,

$$\sum_1^n f_i = 1$$

n - amount of size groups by results of trawling.

Surface density values of fishes all size groups was computed as:

$$\rho = \sum_1^n \rho_i$$

In turn the acoustic back-scattering cross section was determined through target strength *(TSi, dB)* under the formula:

$$\sigma_i = 4\pi \cdot 10^{TS_i/10};$$

For recalculation *li (cm)* - length of pollock *(biological characteristic)* in the appropriate to it target strength of fish *(the acoustic characteristic of reflective ability a fish)* was used the equation *(Traynor, 1996):*

$$TS_i = 20 \cdot Log_{10}[l_i] - 66;$$

During biomass estimation a method of selective processing of acoustic data was used. It is caused by that at the system, regular collection of acoustic data in a course echo sounding take place large variations of echo-intensity. The essence of a method is, that all echo-intensity *(density)*, survey received in region, are distributed on "*n*" of numerical intervals *(j=1,2,3,..., n - gradation)*. Let, the area of region is equal "*S*", total of elementary sampling distance unit *(ESDU)* in region is equal "*N*", the amount of *ESDU* with echo-intensity in a numerical interval "*j*" is equal "*Nj*". It's suggested, that the area, occupied by echo-intensities in the interval "*j*", is equal:

$$S_j = \frac{N_j}{N} \cdot S$$

In this case dispersion and error at processing become less significant in comparison with classical ways of processing, also spatial influence of autocorrelation between acoustic measures decreases, as datas in each numerical interval "*j*" can get echo-intensities from different places of region.

The essential difficulties of detection and quantitative estimation arise during the work with semi-demersal of concentration in habit. By virtue of the various reasons they only are partially registered by echo sounders. To estimate such concentration can be possible only by a echo integration-trawl way *(K.I. Yudanov, 1992.)*. Taking into account, that vertical opening of bottom trawl was 4 m, it was made a decision to carry out echo-integration by two channels: pelagic and bottom *(4-0.5 m to the bottom)*. During result processing of area back scattering coefficient *Sa* $(m^2/mile^2)$ in the second channel was multiplied on appropriate factor of fish masking. This factor was computed as the relation of density, received by results of trawlings, to density under the indications of echo-intergators in the same layer.

To interpolate fish surface density values, the geostatistical gridding method of "Kriging", as recommended *FAO* a method of fields construction of biomass distribution by results of EIT surveys was used.

Biomass of fish aggregations is calculated as:

$$W = \sum_{1}^{n} W_j = \sum_{j}^{n} \rho_j \cdot S_j;$$

where: W_j – biomass in each gradation or on each part of region, (tons);

n – number of gradation or parts of region.

Dispersion of density values $([ton/mile^2]^2)$ in each gradation:

$$D_j^2 = \frac{\sum_{1}^{m_j} [\rho_j - \rho_i]^2}{m_j - 1};$$

where: ρ_j - mean value of density, appropriate *"j"-th* gradation,

$$\rho_j = \frac{\sum_{1}^{m_j} \rho_i}{m_j};$$

where: ρ_i - current value of density in *"j"-th* gradation, $(tons/mile^2)$;

m_j - number of datas, appropriate *"j"-th* gradation.

Error of biomass estimation of fishes on all region was calculated under the formula:

$$\varepsilon_w = \pm t(m) \cdot \sqrt{\sum_1^n \frac{D_j^2 \cdot S_j^2}{m_j}};$$

$$m = \sum_1^n m_j;$$

where: *t(m)* - value of Student *t*-distribution.

Software used at calculations *(Excel, Surfer)*, and also the developed programs of thematic data processing provide calculation of errors of biomass estimations of fishes as on each gradation, and on the whole region. However it is necessary to mean, that the getting errors were calculated by the account only variations of integrals *(density)* of fish aggregations inside gradations and on region of surveying, i.e. are not complete errors, the calculation of which is impossible practically at the moment.

Acoustic data were collected using a Simrad EY500 echo-sounding system operating at 38 kHz. Specifications of the acoustic system during the present servey were following:

- pulse duration - 3.0 ms (Long);
- band width - narrow (0.38 kHz);
- absorption loss coefficient - 10 dB/km;
- TVG function - 20LogR;
- TS threshold = -60 dB;
- Sv threshold = -70 dB;
- sound velocity - 1490 m/s.

The echo sounder was calibrated using a 60 mm copper standard sphere with a TS of –33.6 dB using the technique described by Foote *et al.* (1987). It was carried out in day time on drift of a vessel in a point with coordinates 61°00,173N and 179 °53,181W. Sphere was suspended on fishing line and sank to 24 meters. The depth to the bottom results according to the echo measurements was 185 meters.

The measurement of a noise level was carried out at various speeds of a movement of a vessel according to the methodical work instructions with echo sounder EY500. Thus mean value of noise power on the antenna of echo sounder, recalculating to 1 W, at speed of a movement of 6 knots was -139.7 db.

During carry out of echo survey ESDU was choose 2.5 miles.

In places of the greatest concentration of fishes was carried out twenty one control trawls, duration on 30 minutes each, on depthes from 87 meters up to 250 meters *(Fig. 1)*.

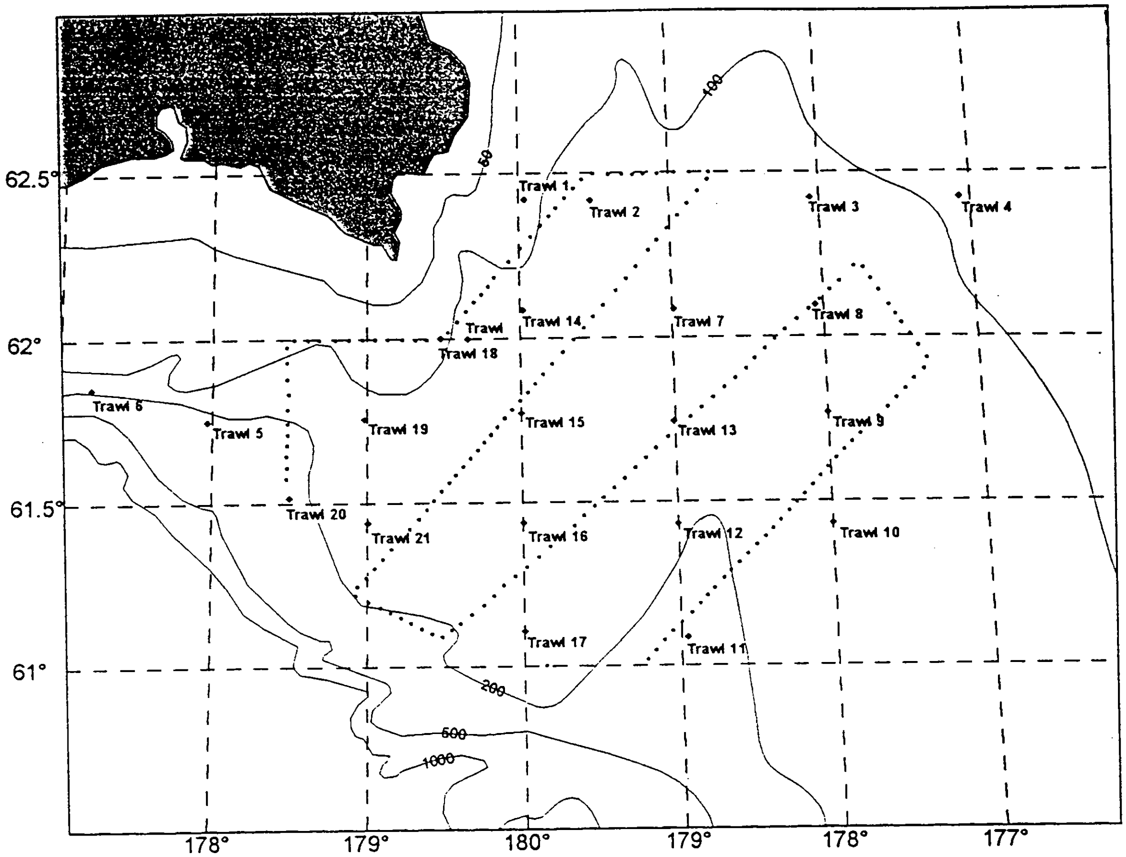

Fig. 1. Plot of hydroacoustic surveys and control trawls, carried out by a vessel "Kaye-Maru № 28 " from October 25 to November 5, 2001.

Walleye pollock was the dominant species (up to 95%) captured in trawls. Average length of a pollock was 35 cm. It the most significant aggregation were observed during conducting of transect №1 in coordinates 61°28.44N; 181°43.37E and №8 in coordinates 61°59.98N; 179°18.92E. The values of *Sa* on this part of transects was 1156 m^2/mile^2 *(109,3 tons/mile^2)* and 1605 m^2/mile^2 *(206,8 tons/mile^2)*.

Echo-integration of the other parts of transects has shown significant decrease of density of registered shoolings – Sa values occasionally exceeded values in 500 m^2/mile^2, at mean: 220 m^2/mile^2 *(st.dev = 266,1 m^2/mile^2)*.

For biomass calculation the dependence of pollock weight versus length was computed from measurements of 823 fish with length from 11 cm to 80 cm *(Table 1)*, with correlation coefficient 0,97:

$$w = 1.74 \cdot 10^{-3} \cdot l^{3.39}$$

,where: w – weight of pollock *(g)*;
l – length of pollock in cm.

Table 1

Average and standard deviation of length and weight of Walleye pollock by results of cath data.

	Mean	St. deviation	Minimum	Maximum
Length(cm)	47,4	11,3	11,0	80,0
Weight(g)	1019,4	813,1	5,0	5500,0

The dependence of weight on length, received by results of measurements of 823 fish is introduced on *Fig. 2.*

At plotting of area density distributions of pollock, for interpolation of area density values, display of a field of biomass distribution, its a quantitative estimation and calculation of each gradation area was used the Serfer software *(Golden Software, USA).*

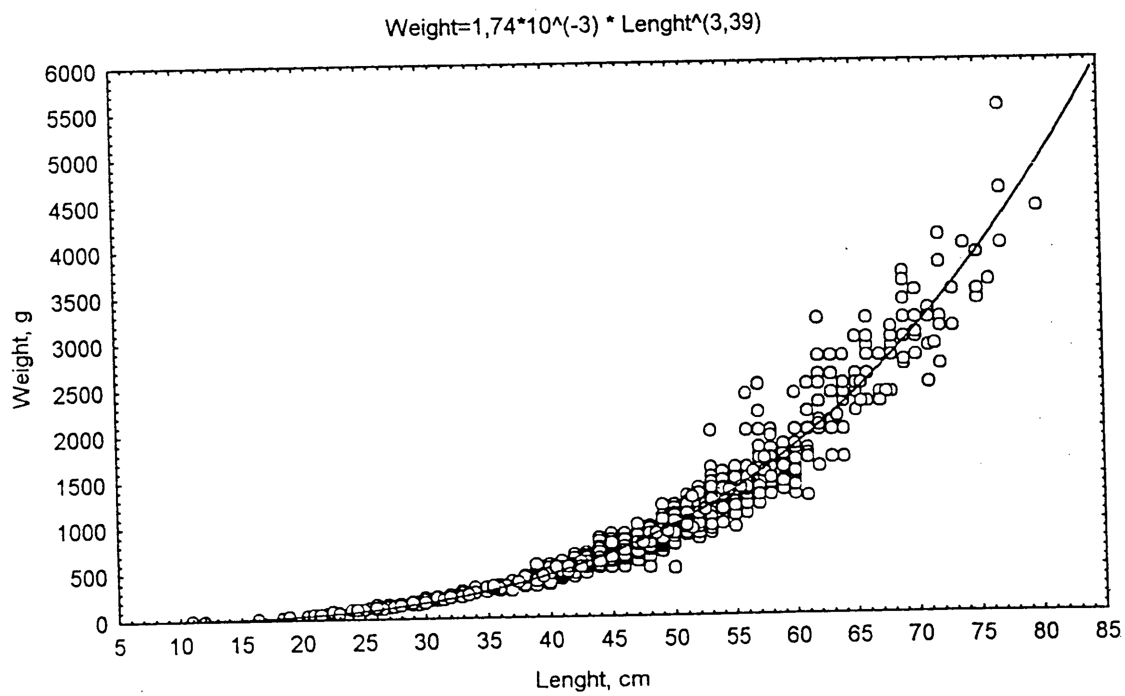

Fig. 2. Dependence of weight from length of Walleye pollock.

To study the spatial structure of pollock distribution, experimental omnidirectional standardised variograms were calculated on the respective estimated fish density. Variograms were fitted by visual inspection to exponential model. Software allows the user to monitor the goodness of fit resulting from the adoption of different choices for the parameters of the model, in order to find the best possible fit. The parameters of the exponential fit to the experimental variogram so obtained were then applied to implement Kriging interpolation method for biomass estimation and mapping purposes.

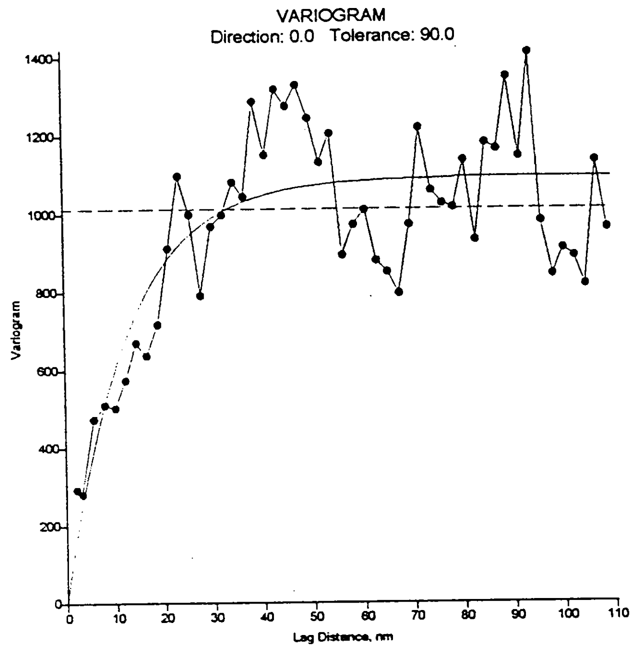

Fig. 3. *Isotropic standardized variogram of area density of Walleye pollock.*

The parameters for calculating of density values in points of a regular grid were following:

- method of interpolation - Kriging;
- model of variogram (see Fig. 3) - Exponential
  (Scale = 1095; length = 14.23; anisotropy = 1.43, 150.2)
- scale of regular grid - 1 mile X 1 mile.

Area density of Walleye pollock by results of echo integration changed in limits from **0.02 up to 206.8 tons/mile2.**

Table 2 represent the biomass calculations results of hydroacoustic survey on the area 10566 mile^2 in the whole water column of fish distribution.

Table 2

Biomass calculations results of Walleye pollock in the whole water column.

Gradation [ton/nm2]	Area [nm2]	Density [ton/nm2]	Biomass [ton]	Confedence Interval[±ton]
0 - 9	2351	4,5	10564,4	281,8
9 - 18	3995	13,2	52666,1	306,2
18 - 27	2015	21,8	43960,9	226,6
27 - 38	903	31,2	28170,8	182,4
38 - 45	277	41,3	11443,1	67,2
>45	1025	73,4	75222,8	1466,5

Total Area = 10566[nm2]
Total Biomass = 222028,1 ± 1553,3[ton]

The distribution of pollock area density (tons/mile^2) plotted on *Fig. 4*.

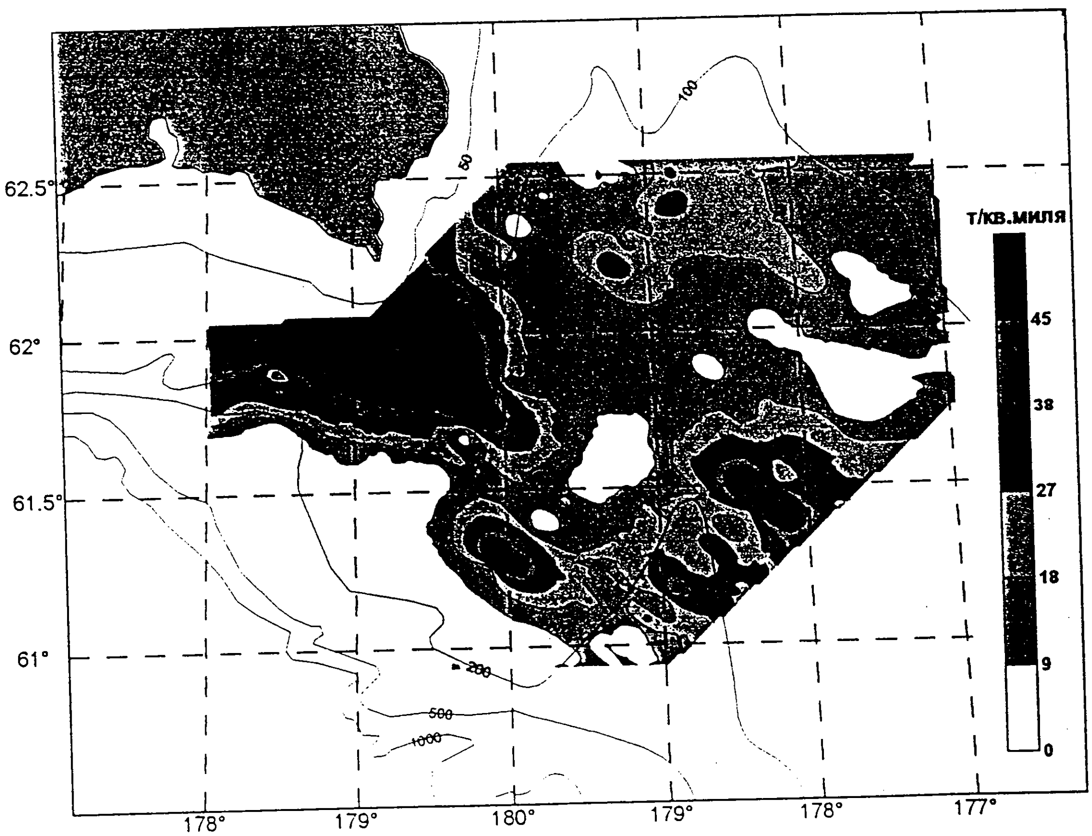

Fig. 4. The distribution of pollock area density (tons/mile^2) of hydroacoustic surveys, carried out by a vessel "Kaye-Maru № 28 " from October 25 to November 5, 2001

Total biomass of Walleye Pollock on data of EIT survey in region was:
222 028 tons on the area 10 566 mile^2.

The estimation of precision of getting results demands the additional analysis spatial variable and use of methods of stochastic modeling, that is a impossible practically in the present moment.

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