Northwest and
Alaska
Fisheries Center

National Marine
Fisheries Service

U.S. DEPARTMENT OF COMMERCE

NWAFC PROCESSED REPORT 80-12

Growth of Larval Walleye Pollock *(Theragra chalcogramma)* in the Eastern Bering Sea, Based on Otolith Increments of Plankton–Caught Specimens from June–July 1979

August 1980

NOTICE

GROWTH OF LARVAL WALLEYE POLLOCK (*THERAGRA CHALCOGRAMMA*) IN THE EASTERN BERING SEA, BASED ON OTOLITH INCREMENTS OF PLANKTON-- CAUGHT SPECIMENS FROM JUNE-JULY 1979

by

Paul D. Walline

Northwest and Alaska Fisheries Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112

CONTENTS

List of Figures and Tables

INTRODUCTION

Annual growth marks on fish otoliths, scales, finrays, and other hard parts have been used for many years in the determination of age and growth of adult fish. For example, Williams and Bedford (1974) discuss the principles and problems involved in the use of otoliths for age determination. This method has been applied in studies of walleye pollock, Theragra chalcogramma (Ishida 1954; LaLanne 1975), but of course it cannot be applied to fish in the first year of life. However, recently a method for determining the age of larval fish by enumerating daily growth increments of the otolith has been developed (Panella 1971; Brother, Mathews, and Lasker 1976). This allows the growth rate of larval fish in the sea to be estimated, and in some cases the method can be extended to postlarval and juvenile fish.

Attention has been focused on the early life history of fishes since mortality rates are highest and most variable from year to year during these first stages. The critical period concept reviewed by May (1974) suggests that larval survival depends upon adequate food when larval yolk supply has been exhausted. Even if food supply is adequate for survival, a reduced growth rate may increase mortality by predation. However, it has not been determined if the growth rate of larval fish varies with food supply. It is possible that food intake is adjusted to maintain a genetically predetermined growth rate (Jones 1976). These hypotheses can be examined by comparing larval growth from areas with differing hydrographic regimes and potential food supplies.

The walleye pollock in the Bering Sea is of special interest because of its large standing stock and fishery. In addition, the results of other oceanographical and ecological studies being made in the Bering Sea at the present time are available and can be used to help interpret growth rate and age-length studies. The most important of these is PROBES (Processes and Resources of the Bering Sea Shelf), an interdisciplinary ecosystem study funded mainly by the National Science Foundation. PROBES is focusing on production of walleye pollock as an example of the transfer of mass and energy in the system. The present investigation is a continuation of the ichthyoplankton studies made at the NWAFC (Northwest and Alaska Fisheries Center) over the past several years and is intended to complement the work of PROBES.

METHODS

Ichthyoplankton was collected from the Bering Sea on a cruise of the NOAA research vessel Miller Freeman from 1 June to 23 July 1979. The main objective of the cruise was to carry out a trawl and hydroacoustic survey of the adult pollock population in the eastern Bering Sea, so the cruise track was intended to cover the entire shelf area once. This allowed samples of larval pollock to be taken from widely separated areas of the eastern Bering Sea (Fig. 1), but allowed only limited time series observations at single locations. The cruise was divided into three legs: I (1 Jun-7 Jun), II (16 Jun-2 Jul), and III (8 Jul-23 Jul). Ichthyoplankton sampling was the primary mission on Leg I. The dates listed demarcate only the periods during which ichthyoplankton sampling occurred.

Ichthyoplankton was collected with three types of nets, a neuston net, a bongo net, and a Tucker trawl. Surface samples were collected using a modified Sameoto neuston sampler with a mouth opening of 30 x 50 cm and a net mesh of 505 µm towed for 10 min at 2-3 knots. Plankton from deeper layers was collected with paired 0.6 m open bongo nets, one with 505 µm mesh and the other with 333 µm mesh. Double oblique tows were made from the surface to slightly more than 200 m depth, or to within 5-10 m of bottom in shallower water. Both of these tows and at least one CTD cast for temperature, depth, and salinity were made at nearly every station. At most stations a 1.0 m square mechanical opening-closing Tucker trawl (Clarke 1969) with three nets of 505 µm mesh was fished. At 6 stations the Tucker trawl was fished in a manner identical to that used with the bongo net. Most of the samples were obtained at the two 48-h diel stations. At these stations a series of Tucker trawl hauls was repeated every 6 h. Each 6 h time period was regarded as a separate station, V01 through V16. The Tucker trawl was fished to sample discrete depth intervals: 100, 60, 40, 25, 15, and 5 m. The 100 m sample was omitted at 8 stations where the bottom depth was 64 m, and at some stations, some of the depths were repeated. On Leg III, 8 July-23 July, the Tucker trawl was often fished horizontally at two or three depths for 5 min each to make hauls combining several depths.

Pollock larvae were picked at sea from the 505 µm mesh bongo samples and from all Tucker trawl hauls. Picking of larvae from a sample was discontinued when 25 were obtained. This procedure

never took longer than 5-6 min. The remaining sample and all neuston samples were preserved in 5% Formalin[1/] (2% formaldehyde) buffered with sodium tetraborate. All of the 333 μm mesh bongo hauls and the larval pollock sorted from samples were preserved in 80% ethyl alcohol. The alcohol was replaced after 24 h for all plankton hauls preserved in it.

In the laboratory the pollock larvae were processed using a method modified slightly from that described by Brothers et al. 1976. These modifications were developed by David Kramer and Richard Methot at the Southwest Fisheries Center. The standard length of each larva was measured and the sagittae removed and placed flat side up on a microscope slide. Since the lapillae for small larvae (<8 mm) were nearly the same size as the sagittae, in most cases all four otoliths were removed and mounted. The use of a polarizing filter and analyzer on the dissecting microscope made it much easier to see the otoliths, some of which were as small as 27 μm. The slides were left to dry and the otoliths from larvae less than 20 mm long were mounted in Protexx, a clear mounting medium. Otoliths from larger larvae were mounted in drops of polyester resin. This allowed larger otoliths to be ground on fine sandpaper and polished with 0.3 μm polishing alumina. This procedure was necessary to clear them enough to make total increment counts. The length of each otolith, either directly in Protexx or after grinding in the polyester resin, was measured under oil

1/ Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

immersion. A video camera was used to project the image from the 100x or 40x microscope objective onto a video screen. The increments are much clearer on the video screen than through the eyepieces, so the accuracy of counts was enhanced. Counts were repeated by a single observer until successive counts differed by fewer than three increments.

Growth rates were determined by two methods. From observations of the smallest larvae found, it was hypothesized that larvae are approximately 4 mm long when the first increment is formed. Therefore, the average growth rate can be calculated from the formula GR = (SL-4)/INC where GR is the average growth rate, SL is the standard length, and INC is the age in days measured by the number of increments. The other method employed was to plot fish length against number of increments for all larvae at a station or in a sample, and find the slope of the line fitted by least squares regression analysis. This should give the average growth rate for the larvae in the sample provided the growth curve is linear and each increment represents a day of age.

It must of course be shown that there exists a strong relation between the number of growth increments and the age of the larvae. Although for most of the species studied by Brothers et al. (1976), the growth increments were shown to be daily in nature, the lag time between hatching and the initiation of increment formation varied. To determine the time at which increment formation begins, a few larvae of known chronological age were obtained and processed in a manner identical to that for

the field-caught larvae. The known age was compared with the number of increments to determine lag times.

RESULTS

At least one ichthyoplankton haul was made at each of 131 stations. At 39 locations pollock larvae were found and removed from the plankton for examination of otoliths (Table 1). Most of the larvae (80%) were caught at the two 48-h diel stations, but some were found as far north as 61°N at Station S117 and some far to the west of the shelf break in deep water at Stations S22, S21, and S24. Relatively small pollock larvae, 10-15 mm, were found at some of the stations far to the north as late as July, which was surprising as larvae at most of the stations on Leg II a month earlier were already larger than 20 mm. Average growth rates calculated by subtracting 4 mm from the standard length and dividing by the number of increments ranged from a low of 0.28 mm/day at Station S101 to a high of 0.53 mm/day at Station V12 (Table 1). Larvae from stations far to the north (S101-S117) on the average grew more slowly than those obtained at the two diel stations in June. The difference is quite small but would amount to a difference in average length of about 10 mm if maintained for 6 months. Mean growth rates at the two diel stations also were slightly different. Larvae at the deeper station (V01-V08) grew an average of 0.38 mm/day while those at the inner station (V09-V16) grew 0.49 mm/day. A simple t-test shows this difference to be highly significant. The larvae found in deep water (S18-S24) grew at a rate close to that found at the outer shelf diel station.

The method used for calculating the growth rates assumes that growth in length is constant with increasing length. This assumption was checked by plotting the standard length of the pollock larvae against the number of increments observed on the otolith (Fig. 2). If both otoliths were analyzed, the average of the two counts was used. The relation between length and age appears to be rectilinear, at least for larvae in the length range 6-30 mm. The regression line fitted by least squares regression analysis explains 96% of the observed variability.

As described earlier, the slope of the line is an estimate of the average growth rate for all the larvae in the plot. The growth rate obtained, 0.35 mm/day, is lower than that obtained above for either of the two 48-h stations. The intercept of this line with the y-axis gives a value of 4.8 mm for a larva with no growth increments. However, smaller larvae have been observed, many with one or two growth increments. Therefore, it appears more consistent with observations to assume a length of about 4 mm for the initiation of increment formation. With this value for the intercept, one obtains an average growth rate of 0.38 mm/day, compared to 0.39 mm/day for the average growth rate from all the stations listed in Table 1.

The ages of many larvae caught on Legs II and III could not be determined directly using these methods (Table 1). When the larvae attain a length of about 20 mm, the otolith begins to become much thicker and more opaque, especially near the center or focus. This problem could be overcome if a reliable estimate of the number of increments in the obscured part of the otolith

could be made. To check the feasibility of such a procedure, the number of increments was plotted against the otolith length (Fig. 3). The relationship is non-linear and fortunately, stronger for smaller otoliths than larger. Provided the part of the otolith which is obscured is not too large, this method can probably be successfully applied to the larger larvae and smaller juvenile pollock.

The growth of larval pollock does not vary greatly with depth (Table 2). Most are caught at depths above 30 m. This is apparent even though the numbers tabulated are the number of pollock picked out and not the total number of pollock in the hauls. Although there are only slight differences in growth rates for samples from the same depth and location at different times, there are large differences in the estimated growth rates of individual larvae, for example the larvae caught at Station V12 at 25 and 40 m. Larvae caught at night grew at the same rate on the average as those caught during the day. Although more larvae were caught at night, the average length, at least for those picked out for age determination, was the same for day-caught as for night-caught larvae (Fig. 4, Table 1).

The temperatures in the upper mixed layer where most of the larvae were caught were the same at the two 48-h stations. At the inner location the surface temperature ranged between 6 and 7°C. A sharp thermocline was observed at about 20 m depth. The bottom layer was well mixed with a temperature about 3.7°C (Fig. 4). At the deeper outer shelf station the surface layer and the bottom layer were separated by a layer 60-70 m thick

exhibiting finestructure, or rapid variations of physical properties with depth (Fig. 5). Temperature and salinity profiles were made twice every 6 h at these stations and showed little change with time. At the inner, shallower station, the surface temperature was more variable, sometimes rising above 8°C. At the stations far to the north, for example S1Ø4, the upper layer had extended to almost 5Ø m in two steps (Fig. 6). The surface temperature was higher than 8°C and the bottom layer was colder than the 3.7°C found at the two 48-h stations. In all, 136 casts were made for salinity, temperature and depth. The complete data set is available from NWAFC (Arthur W. Kendall).

Of the 15 fish of known age available for validating the method, only 5 had readable otoliths. The oldest larva available was 13 days old and had 1Ø increments. Of four larvae 8 days old, two had 5 increments and two had 4 increments. Based on this limited sample, increment formation was assumed to begin 3-4 days after hatching. These larvae were not fed successfully, so computed growth rates are practically meaningless.

DISCUSSION

Because so few fish of known age were available, the daily nature of the growth increments could not be adequately demonstrated. However, Brothers et al. (1976) suggest that observed increments are daily rings for several species of fish including two species of *Merluccius* which are closely related to *Theragra*. They conclude that the method should be applicable to most species. Although the possibility of a growth interruption

during the winter casts doubt on the assumption that the increments are daily for juvenile pollock, it should be acceptable for larvae.

The determination of the timing of the initiation of increment formation must be done experimentally. Brothers et al. (1976) demonstrated species dependent variations in the timing. For anchovy, increment formation began at yolk absorption and for Leuresthes tenuis at hatching. If a lag time after hatching is present, its length will depend on temperature and possibly other environmental parameters. This will introduce complications in attempts to assign hatching dates to field-caught larvae. It has been shown that for anchovy and sardines biological events such as development of functional jaw occur at the same size regardless of age (Zweifel and Lasker 1976). From this it can be argued that increment formation begins at the same size for all pollock larvae. The age of the larvae at that size will depend on temperature. Larvae grown in the laboratory under various conditions need to be examined to increase the accuracy with which ages can be assigned to field-caught larvae.

Hamai, Kyushin, and Kinoshita (1974) raised pollock larvae in the laboratory under several feeding regimes. Growth in length was at most 1 mm after 40 days. Unfed larvae grew an average of 0.5 mm during the experiment. It can be concluded that none of the larvae were feeding at rates comparable to those likely in the sea, but the study does indicate that at least some larvae can survive on yolk-sac nutrition for periods up to a month. This result is consistent with the findings of Clarke (1979). It

is therefore necessary to find out whether increment formation is affected by starvation of yolk-sac larvae. Many more larvae raised in the laboratory under various feeding regimes need to be examined to elucidate the size and age at which increment formation begins and to determine whether starvation affects the formation of increments. Samples of larvae of known age fed at rates allowing growth comparable to that observed in the sea are needed to be sure that increment formation is not retarded by lack of food.

The average growth rates for larval pollock in this study are in the middle of the range of growth rates found by Cooney, English, and Nishiyama (1978) for larval pollock in the eastern Bering Sea. They determined growth rates by identifying cohorts of larval pollock and measuring their average lengths on successive sampling dates. Growth rates ranged from 0.1 mm/day for larvae less than 10 mm to 0.5-0.7 mm/day for larvae between 15 mm and 100 mm.

Although the average growth rates reported here are similar to those reported for other fish, the growth curve is usually fitted by a more complicated expression than a linear regression line (Methot and Kramer 1980). Zweifel and Lasker (1976) suggest that, based on data for anchovy, the growth of larval fish can be represented by a Gompertz-type curve. They note that "a moderate increase in length during the interval following hatch that is followed by a period of minimal growth" is almost always observed. This is not present in the plot of length against number of increments shown here, possibly because only a few

newly hatched larvae were caught. In addition, increment formation does not begin immediately after hatching, so this part of the growth curve must be determined from laboratory-hatched fish. Although a Gompertz-type or other non-linear curve could be fitted to the data, for the narrow length range in this study, the linear approximation seems to be adequate. When newly hatched larvae and juvenile pollock are included in the growth curve, this approximation will probably no longer be as useful. For individual stations the linear approximation also yielded relatively high correlation coefficients, in most cases greater than 0.90. However, it is possible that some of the difference observed between the two 48-h stations is due to the error caused by this approximation as the average lengths of the larvae at the two stations differ considerably.

The growth curve of pollock from 4 to 30 mm does not show an inflection point similar to that observed by Strusaker and Uchiyama (1976) for nehu. This is consistent with the observation that pollock larvae do not undergo a drastic metamorphosis nor do they dramatically alter their diet as they grow (Cooney, Clarke, and Walline in prep.).

The physical oceanography of Bristol Bay has been described by Coachman and Charnell (1979). Three basic water masses mix in Bristol Bay: coastal water, shelf water, and Alaska Stream/Bering Sea water. The large scale exchange taking place is the onshore flow of Alaska Stream/Bering Sea water in a bottom layer and the movement of shelf water seaward at mid-depths. The shelf water (colder and less saline) mixes with oceanic water

(warmer and more saline) across a wide transition zone. Since advection is very low, only wind and tidal motion are present to supply mixing energy. Differences in the importance of these sources of mixing energy across the shelf cause the formation of fronts. Three fronts, regions of enhanced horizontal gradients of properties, divide the shelf into four regions, the Oceanic Domain, the Outer Shelf Domain, the Central Shelf Domain, and the Coastal Domain. The fronts are related to specific depth contours. The outer front is located near the 170 m depth contour, the middle front at the 100 m contour and the inner front at about the 50 m contour. In the Coastal Domain wind mixing reaches to the bottom and temperature and salinity are nearly homogeneous with depth. In the Central Shelf Domain the two independent energy regimes nearly meet. This results in a two-layer structure. In the Outer Shelf Domain, the two energy regimes are separated by a layer without significant mixing energy. In this depth range, interleaving of layers of water a few meters thick (finestructure) is observed.

Based on the vertical distribution of temperature and salinity and the bottom depth, Stations V01-V08 can be assigned to the Outer Shelf Domain and Stations V09-V16 can be assigned to the Central Shelf Domain. Temperature in the surface layer was similar at the two locations but there are important differences in the zooplankton characterizing the two domains (Cooney 1979). In the Central Shelf Domain small copepods, mainly Oithona and Pseudocalanus, are abundant. The eggs and nauplii of these species are ideal food for survival of newly hatching pollock

larvae. At the deeper location, in the Outer Shelf Domain, larger oceanic copepods, especially Calanus, are abundant. As pollock larvae grow, they begin to feed on adult copepods and juvenile euphausiids, and the large oceanic copepods are excellent food (Cooney 1979; Clarke 1978). These observations are consistent with the growth rates measured in this study. The conditions at the inner location are favorable for survival of newly hatching larvae, and the small larvae present were growing rapidly. At the outer location the larvae survived to an average length of 16-18 mm without the benefit of high concentrations of Pseudocalanus and Oithona, and the growth rates averaged over this period are lower than those observed for larvae growing at the inner location. It might be expected that growth would be higher for larvae longer than 20 mm at the outer station where larger food items are more abundant.

At the stations far to the north (S101-S117), although the surface temperature is higher, the mixed layer is much deeper. This would result in a greater dispersal of food items and may possibly explain the somewhat lower growth rates at these stations. It is hard to understand how these larvae found food in sufficient concentration to survive the period of first feeding at all. The presence of pollock larvae at these stations was unexpected, and they may not be from the same stock as those found south and east of the Pribilofs.

Finally, we found the variability of growth rates at individual stations to be higher than that between stations. The variability at a station includes random error in the ageing

method as well as small scale variations integrated by the nets. It appears that small scale changes in the environment are as important as the large scale differences observed between stations, until one considers that no larvae at all were found at more than half the stations. Possibly if the larvae cannot maintain some minimum growth rate, they are unable to survive.

Brothers, E.B., C.P. Mathews and R. Lasker. 1976. Daily growth increments in otoliths from larval and adult fishes. Fish. Bull., U.S. 74: 1-8.

Clarke, M.R. 1969. A new midwater trawl for sampling discrete depth horizons. J. Mar. Biol. Ass. U.K. 49: 945-960.

Clarke, M. 1978. Some aspects of the feeding biology of larval walleye pollock, Theragra chalcogramma (Pallas), in the southeastern Bering Sea. M.S. Thesis, Univ. of Alaska, Fairbanks. 44 p.

Coachman, L.K. and R.L. Charnell. 1979. On lateral water mass interaction-a case study, Bristol Bay, Alaska. J. Phys. Oceanog. 9: 278-297.

Cooney, R. Ted, M.E. Clarke and P. Walline. 1980. Food dependencies for larval, post-larval, and juvenile walleye pollock, Theragra chalcogramma (Pallas), in the southeastern Bering Sea. in prep.

Cooney, R.T., T.S. English and T. Nishiyama. 1978. Upper trophic level ecology with emphasis on juvenile pollock in the Southeast Bering Sea. In PROBES: Processes and resources of the Bering Sea Shelf, Progress Report 1978, p. 241-405.

Cooney, R.T. 1979. Seasonal distribution and abundance of zooplankton and micronekton in the Southeast Bering Sea. In PROBES: Processes and resources of the Bering Sea Shelf, Progress Report 1979, vol. I, p. 162-204.

Hamai, I., K. Kyushin and T. Kinoshita. 1974. On the early larval growth, survival and variations of body form in the walleye pollock, Theragra chalcogramma (Pallas), in rearing experiment feeding the different diets. Bull. Fac. Fish. Hokkaido Univ. 25: 20-35.

Ishida, T. 1954. On the age determination and morphometrical differences of the otolith of Alaska pollock in the Hokkaido coast. Bull. Hokkaido Reg. Fish. Res. Lab. 11: 36-67. (In Japanese with English summary.)

Jones, R. 1976. Growth of fishes. In D.H. Cushing and J.J. Walsh (eds.), The ecology of the seas, p. 251-279. W.B. Saunders Co., Philadelphia.

LaLanne, J.J. 1975. Age determination of walleye pollock (Theragra chalcogramma) from otoliths. U.S. Dep. Commer., NOAA, NMFS, Seattle, Washington. Processed rep. 19 p.

May, R.C. 1974. Larval mortality in marine fishes and the critical period concept. In J.H.S. Blaxter (ed.), The early life history of fish, p. 3-19. Springer-Verlag, Berl.

Methot, R.D., Jr. and D. Kramer. 1980. Growth of northern anchovy, Engraulis mordax, larvae in the sea. Fish. Bull., U.S. 77: 413-423.

Panella, G. 1971. Fish otoliths: daily growth layers and periodical patterns. Science 173: 1124-1127.

Struhsaker, P. and J.H. Uchiyama. 1976. Age and growth of the nehu, Stolephorus purpureus (Pisces: Engraulidae), from Hawaiian Islands as indicated by daily growth increments of sagittae. Fish. Bull., U.S. 74: 9-17.

Williams, T. and B.C. Bedford. 1974. The use of otoliths for age determination. In T.B. Bagenal (ed.), Ageing of fish, p. 114-123. Unwin Bros., Ltd.

Zweifel, J.R. and R. Lasker. 1976. Prehatch and posthatch growth of fishes-a general model. Fish. Bull., U.S. 74: 609-621.

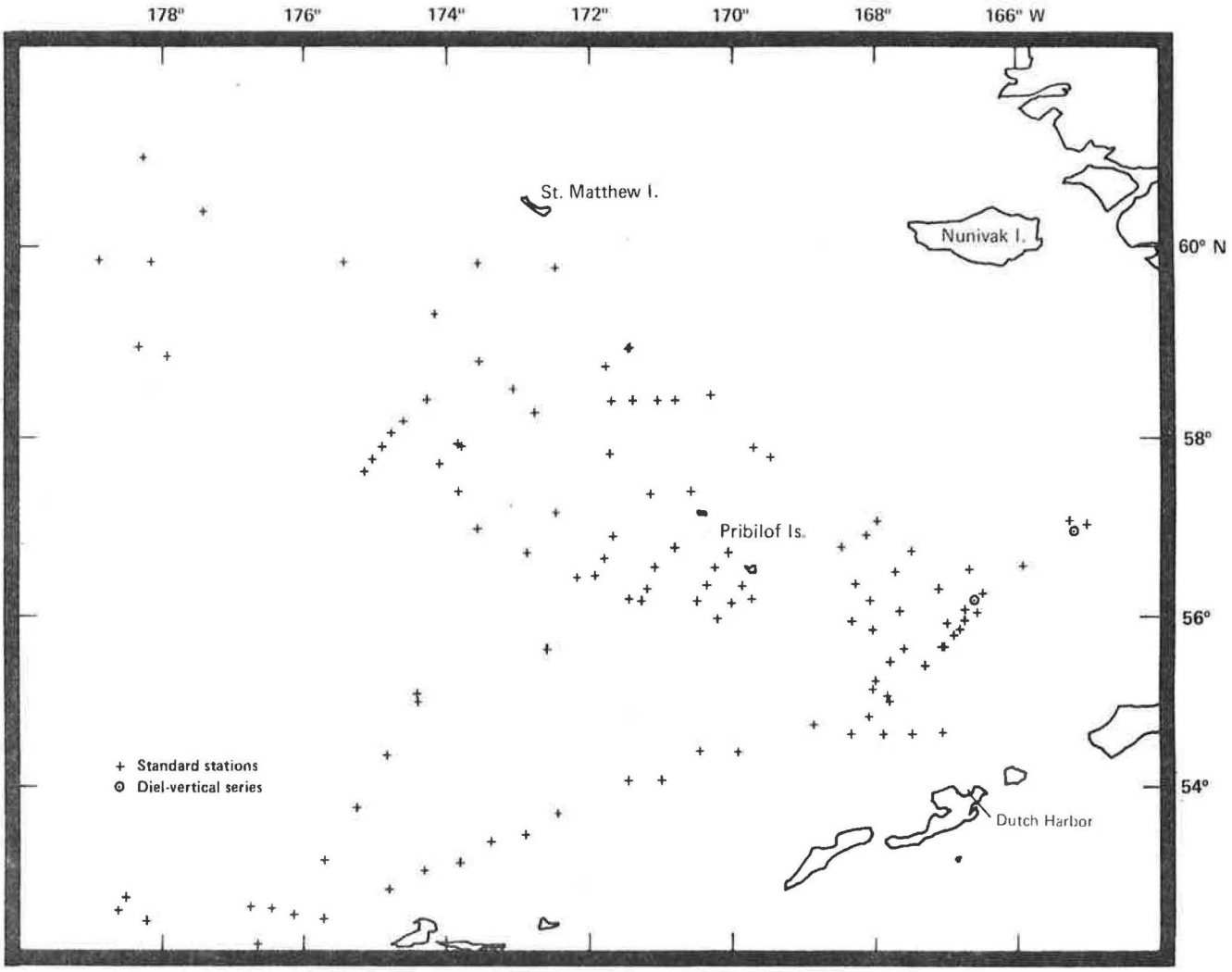

Figure 1. Distribution of sampling stations for larval pollock, RV Miller Freeman, Cruise 3MF79, 1 JUN-23 JUL 1979.

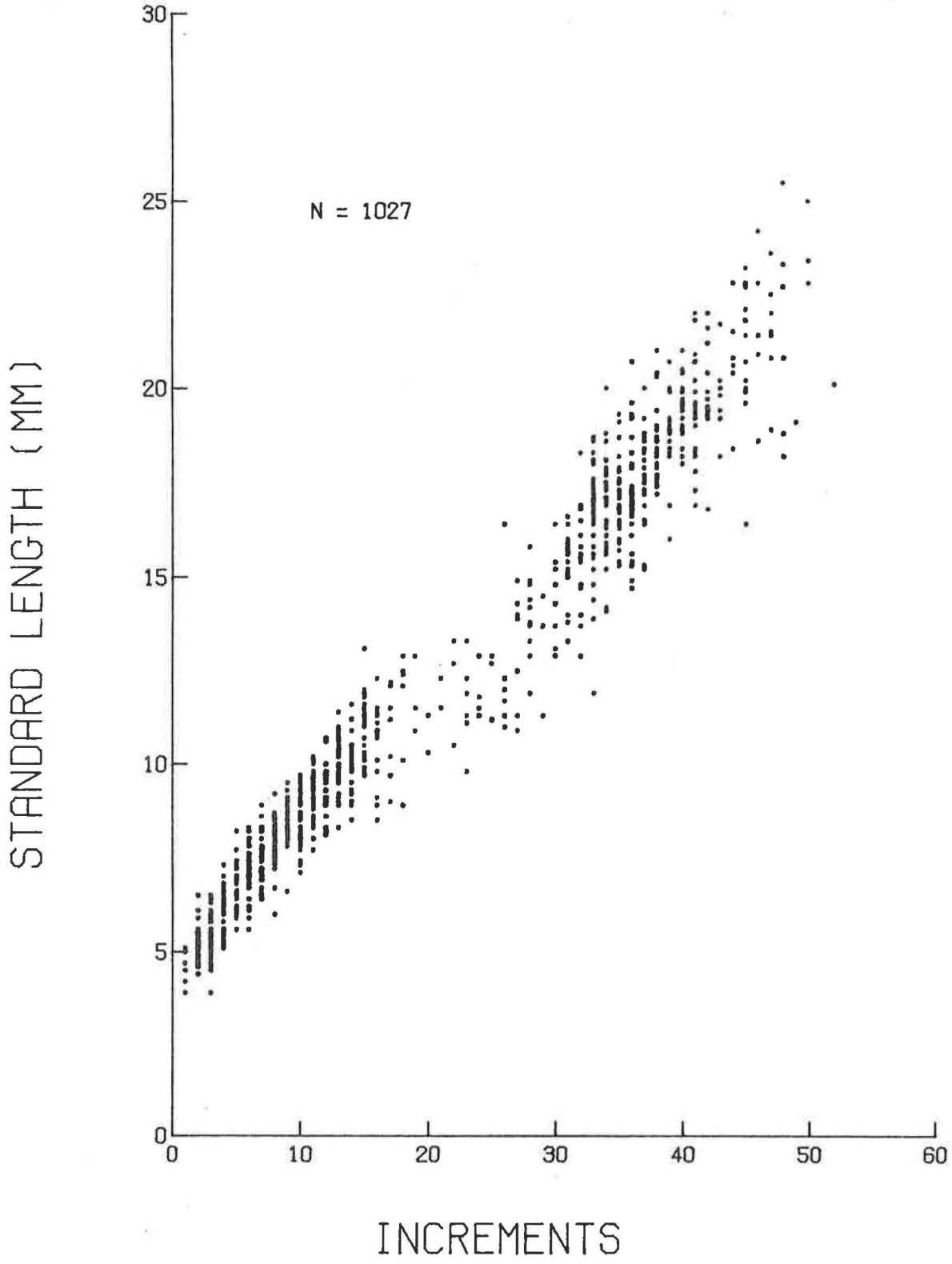

Figure 2. Standard length of larval pollock in millimeters plotted against the number of daily growth increments observed in the otoliths. Each point represents one larva.

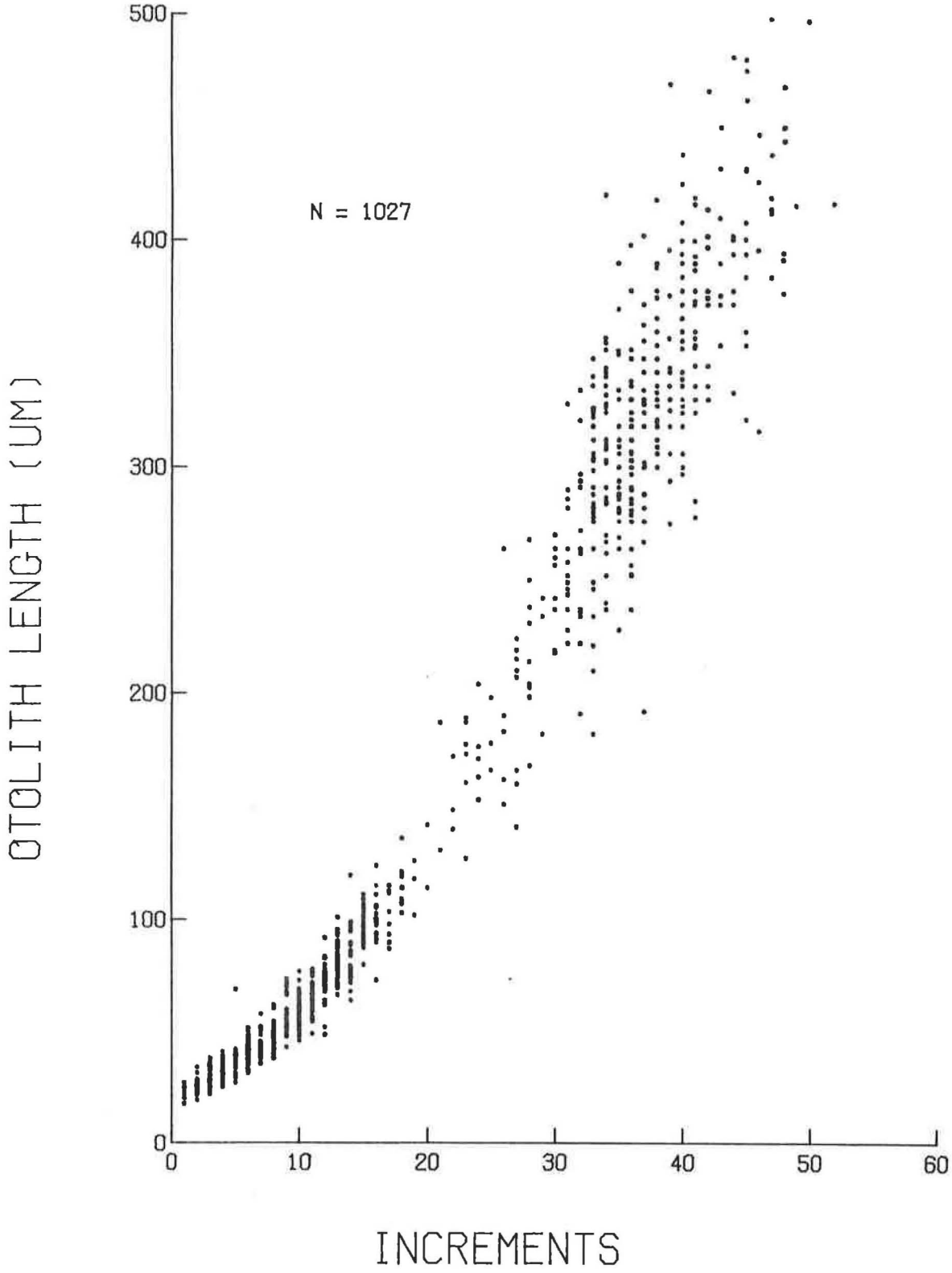

Figure 3. Otolith length in micrometers plotted against the number of daily growth increments observed. Each point represents one larva.

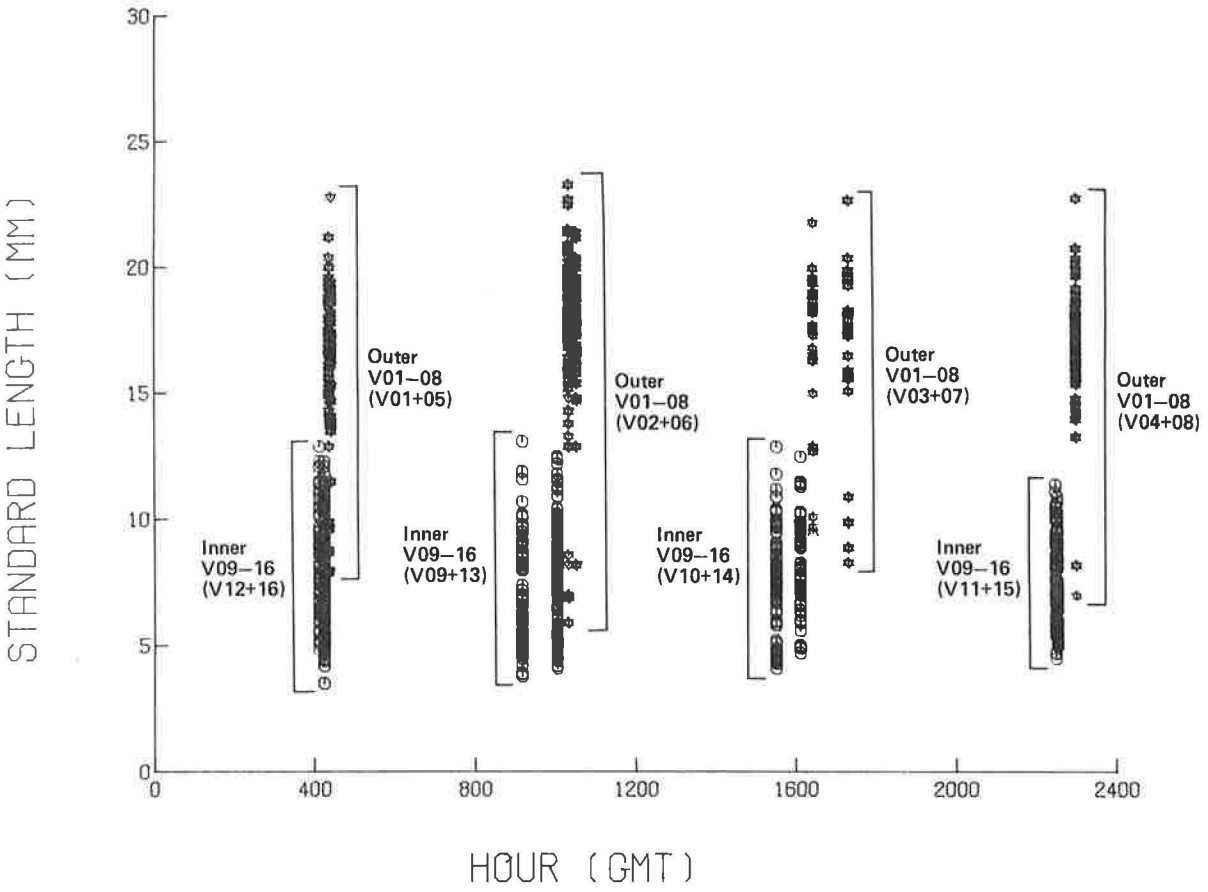

Figure 4. Standard length of larval pollock in millimeters plotted against the time that the Tucker trawl series was initiated for Stations VØ1-V16.

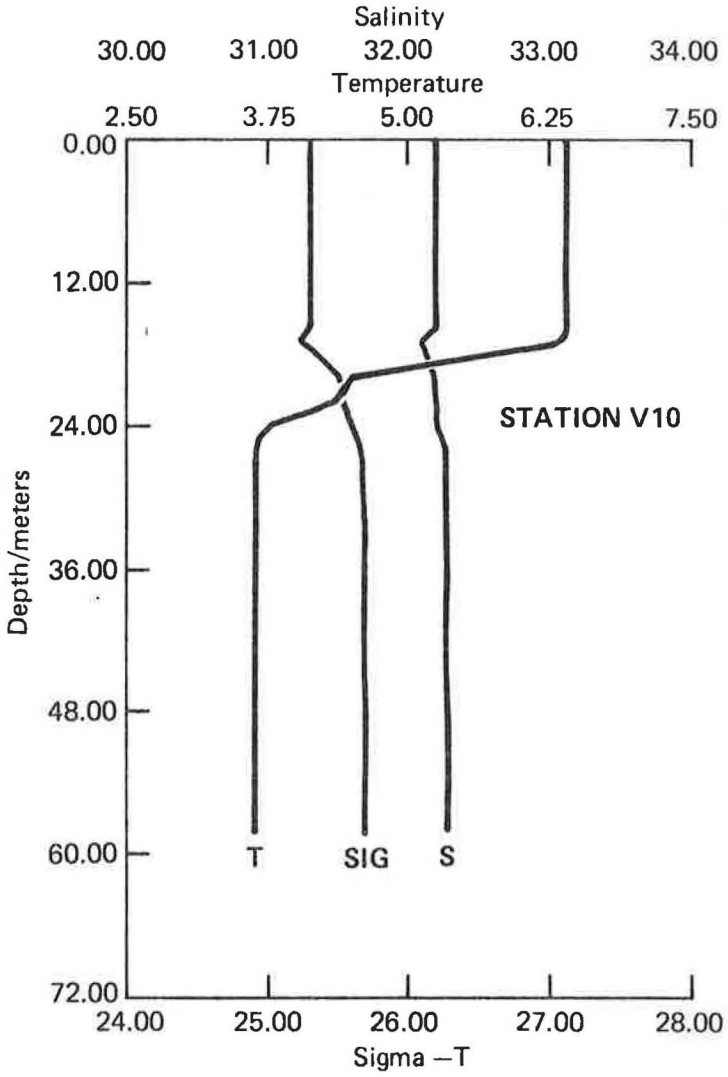

Figure 5. Temperature, salinity, and density profile at Station V1Ø.

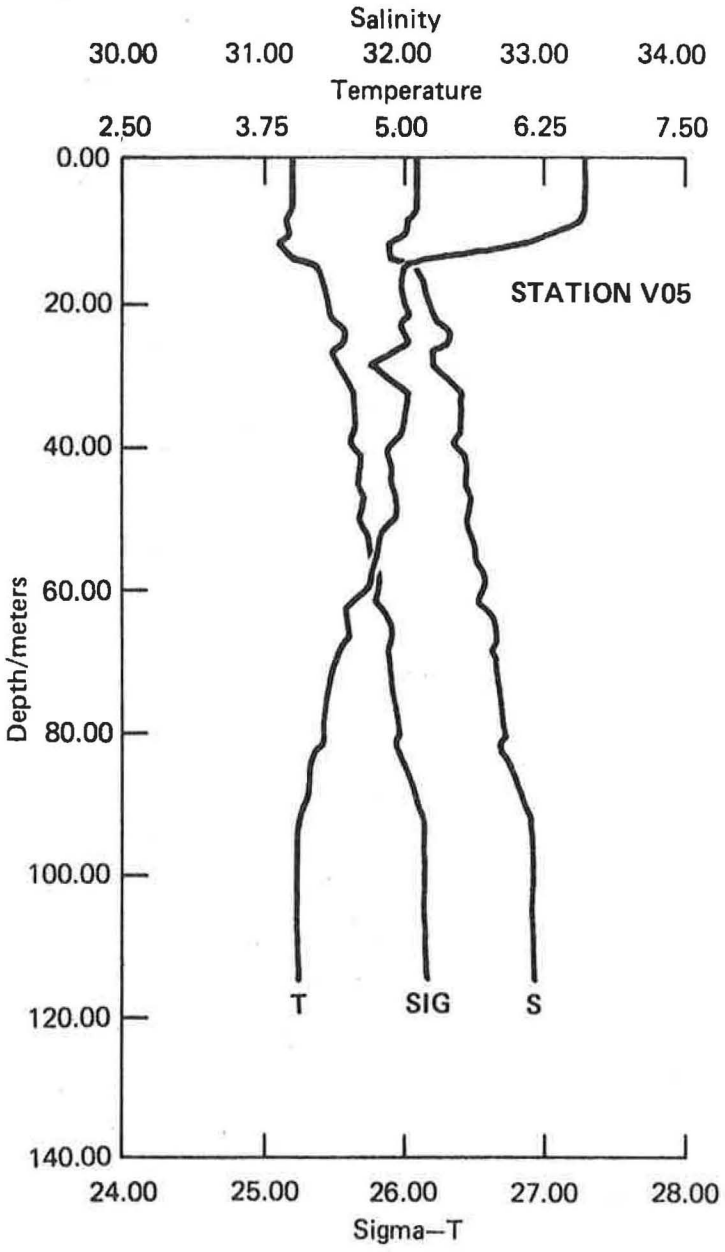

Figure 6. Temperature, salinity, and density profile at Station VØ5.

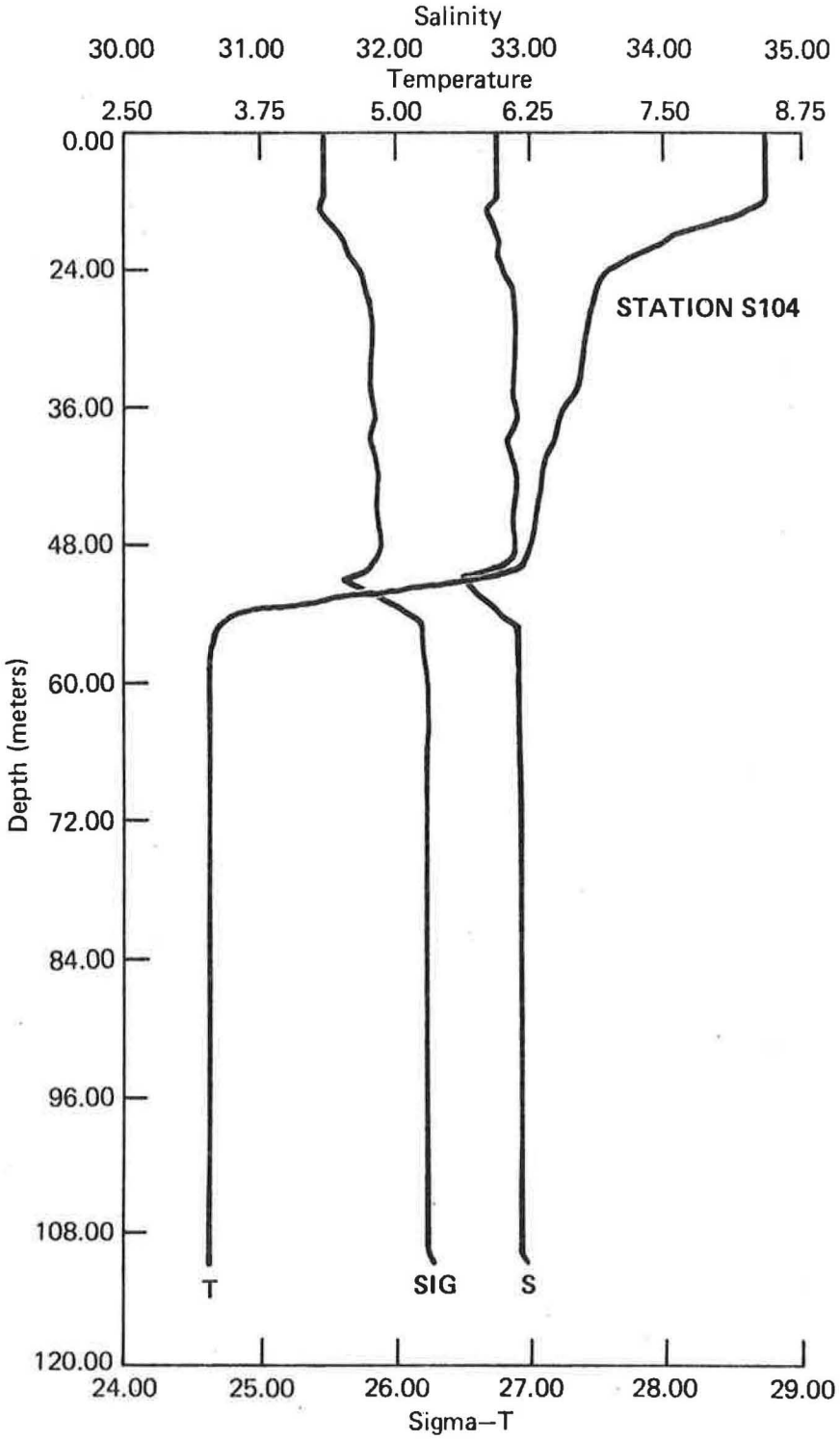

Figure 7. Temperature, salinity, and density profile at Station S1Ø4.

Table 1. Data associated with larval walleye pollock collections which were used for otolith increment determinations.

Station No.	Date (GMT)	Lat. (N)		Long. (W)		No. of Fish	Average Length (mm, SL)	Average Growth Rate (mm/day ± S.D.)
		o	'	o	'			
S07	1 Jun	55	26.8	167	18.4	3	18.3	0.36 ± 0.01
S08	1 Jun	55	39.3	167	3.9	14	17.7	0.36 ± 0.02
S09	2 Jun	55	51.0	166	48.7	3	19.0	0.40 ± 0.04
V01	2 Jun	56	3.3	166	33.8	40	17.3	0.35 ± 0.04
V02	2 Jun	56	2.9	166	32.2	41	17.8	0.39 ± 0.04
V03	2 Jun	56	3.1	166	35.0	29	16.3	0.38 ± 0.03
V04	2 Jun	56	3.1	166	35.7	33	16.3	0.37 ± 0.05
V05	3 Jun	56	3.0	166	34.3	47	16.2	0.39 ± 0.04
V06	3 Jun	56	3.5	166	34.1	82	17.6	0.39 ± 0.07
V07	3 Jun	56	3.0	166	34.0	27	16.9	0.39 ± 0.02
V08	3 Jun	56	3.2	166	34.2	21	18.0	0.39 ± 0.02
V09	4 Jun	57	3.3	165	1.1	63	6.9	0.46 ± 0.15
V10	4 Jun	57	3.0	165	1.3	56	7.9	0.46 ± 0.10
V11	4 Jun	57	3.0	165	2.3	49	7.6	0.52 ± 0.11
V12	5 Jun	57	2.7	165	1.6	107	7.5	0.53 ± 0.15
V13	5 Jun	57	2.9	165	2.8	105	7.8	0.50 ± 0.12
V14	5 Jun	57	2.8	165	2.4	47	8.4	0.46 ± 0.10
V15	5 Jun	57	3.8	165	3.2	56	7.8	0.50 ± 0.09
V16	6 Jun	57	2.9	165	1.6	87	8.3	0.49 ± 0.09
S11	6 Jun	57	5.2	165	15.4	21	13.8	0.41 ± 0.06
S12	6 Jun	56	34.9	165	54.6	22	20.6	0.42 ± 0.03
S13	6 Jun	55	10.2	168	28.3	11	19.6	0.40 ± 0.04
S14	7 Jun	54	48.0	169	28.0	1	14.5	0.40
S17	7 Jun	53	41.3	172	28.8	1	17.1	0.36
S18	7 Jun	53	20.9	173	23.4	6	15.8	0.35 ± 0.03
S19	8 Jun	53	0.8	174	19.4	7	16.0	0.35 ± 0.04
S21	16 Jun	52	2.9	175	43.4	1	13.6	0.33
S22	16 Jun	52	45.6	174	48.5	2	15.9	0.31 ± 0.02
S24	16 Jun	53	26.0	172	53.8	2	16.6	0.29 ± 0.01
S26	17 Jun	54	25.8	169	55.3	1	21.7	0.36
S32	19 Jun	55	57.3	166	44.6	9	24.4	0.41 ± 0.02
S33	19 Jun	56	16.2	166	29.6	1	24.5	0.37
S40	21 Jun	56	32.2	166	40.7	3	25.8	
S41	22 Jun	56	10.9	168	5.2	1	20.9	0.37
S44	23 Jun	56	23.2	168	15.6	1	30.4	0.41
S57	26 Jun	56	11.0	170	30.2	3	26.8	0.44 ± 0.03
S63	28 Jun	56	39.4	171	47.2	1	23.9	0.42
S66	30 Jun	54	23.0	174	50.7	2	28.1	0.40 ± 0.01
S71	1 Jul	52	33.2	176	44.5	1	20.2	0.36
S85	11 Jul	57	43.9	174	6.4	1	33.0	0.41
S87	12 Jul	57	54.2	169	41.1	1	42.0	0.45
S99	15 Jul	57	45.9	175	2.5	1	36.6	0.54
S101	16 Jul	58	45.9	171	46.5	2	13.0	0.28 ± 0.05
S102	16 Jul	58	58.4	171	26.5	6	12.9	0.30 ± 0.02
S103	16 Jul	59	7.7	171	5.7	3	13.7	0.30 ± 0.05
S104	16 Jul	58	58.0	171	26.6	17	11.2	0.31 ± 0.06
S110	19 Jul	59	19.2	174	10.7	3	9.5	0.36 ± 0.09
S112	20 Jul	59	49.4	173	34.2	2	23.9	0.38
S113	20 Jul	59	50.4	175	26.5	5	32.4	0.41 ± 0.02
S115	21 Jul	59	50.7	178	8.9	3	11.1	0.32 ± 0.04
S116	22 Jul	60	22.2	177	25.5	3	10.5	0.34 ± 0.09
S117	23 Jul	60	54.4	178	16.7	8	12.9	0.31 ± 0.02

Table 2. Growth rates of walleye pollock larvae by time and depth at the diel stations.

Station No.	Date (GMT)	Time	Depth (m)	Net[1/]	No. of Fish[2/]	Average Growth Rate (mm/day ± S.D.)	Average Length (mm, SL)
VØ1	2 Jun	Ø7Ø1	15	TT	25	Ø.35 ± Ø.Ø4	16.8
		Ø6Ø4	4Ø	TT	2	Ø.37 ± Ø.Ø8	21.4
		Ø441	1ØØ-Ø	TT	5	Ø.35 ± Ø.Ø2	16.2
		Ø337	1ØØ-Ø	BON	8	Ø.36 ± Ø.Ø2	18.7
VØ2	2 Jun	13Ø2	15	TT	15	Ø.39 ± Ø.Ø5	17.5
		1223	25	TT	8	Ø.37 ± Ø.Ø4	16.3
		1149	4Ø	TT	12	Ø.4Ø ± Ø.Ø2	19.3
		1Ø52	1ØØ-Ø	TT	6	Ø.4Ø ± Ø.Ø2	18.5
VØ3	2 Jun	1927	15	TT	2Ø	Ø.37 ± Ø.Ø2	17.4
		1858	25	TT	3	Ø.42 ± Ø.Ø5	8.7
		1733	1ØØ-Ø	TT	5	Ø.4Ø ± Ø.Ø2	17.8
		16Ø9	1ØØ-Ø	BON	1	Ø.44	13.8
VØ4	2-3 Jun	ØØ56	15	TT	25	Ø.36 ± Ø.Ø2	16.9
		ØØ26	25	TT	6	Ø.4Ø ± Ø.Ø4	15.2
		23Ø2	1ØØ-Ø	TT	2	Ø.51 ± Ø.21	11.8
VØ5	3 Jun	Ø635	15	TT	22	Ø.38 ± Ø.Ø2	17.6
		Ø6Ø7	25	TT	4	Ø.51 ± Ø.Ø4	8.8
		Ø436	1ØØ-Ø	TT	18	Ø.38 ± Ø.Ø2	14.9
		Ø355	1ØØ-Ø	BON	3	Ø.4Ø ± Ø.Ø2	18.5
VØ6	3 Jun	1236	5	TT	1	Ø.58	6.9
		1215	15	TT	18	Ø.38 ± Ø.Ø2	18.1
		115Ø	25	TT	31	Ø.37 ± Ø.Ø2	18.3
		1122	4Ø	TT	7	Ø.53 ± Ø.15	12.2
		11Ø1	6Ø	TT	1	-	13.3
		Ø953	113-Ø	BON	25	Ø.37	18.4
VØ7	3 Jun	1914	5	TT	1	Ø.39	9.5
		185Ø	15	TT	16	Ø.38 ± Ø.Ø3	16.7
		1828	25	TT	3	Ø.38 ± Ø.Ø1	19.2
		1ØØ1	114-Ø	BON	7	Ø.39 ± Ø.Ø2	17.5
VØ8	3-4 Jun	ØØ48	15	TT	9	Ø.38 ± Ø.Ø2	16.7
		ØØ22	25	TT	3	Ø.39 ± Ø.Ø2	2Ø.6
		23Ø3	1ØØ-Ø	TT	9	Ø.39 ± Ø.Ø2	18.3
VØ9	4 Jun	1Ø4Ø	15	TT	29	Ø.51 ± Ø.Ø7	8.4
		1Ø17	25	TT	13	Ø.49 ± Ø.23	5.2
		Ø954	4Ø	TT	11	Ø.42 ± Ø.12	5.3
		Ø846	6Ø-Ø	BON	1Ø	Ø.36 ± Ø.19	6.7

Table 2. (cont.)

V10	4 Jun	1820	5	TT	(1)	-	4.8
		1758	15	TT	29	0.50 ± 0.10	8.8
		1710	25	TT	11	0.45 ± 0.08	8.0
		1617	40	TT	(7)	-	5.0
		1530	60-0	TT	16	0.42 ± 0.11	7.1
V11	4-5 Jun	0006	15	TT	21	0.48 ± 0.07	8.8
		0041	30	TT	20	0.52 ± 0.10	7.4
		2235	60-0	BON	8	0.63 ± 0.12	6.1
V12	5 Jun	0545	15	TT	28	0.51 ± 0.08	8.7
		0623	15	TT	23	0.67 ± 0.17	6.8
		0520	25	TT	1	0.20	5.1
		0455	40	TT	1	0.77	5.7
		0424	60	TT	6	0.42 ± 0.06	6.9
		0359	85-0	BON	19	0.58 ± 0.19	6.7
		0649	85-0	TT	29	0.47 ± 0.07	8.5
V13	5 Jun	1157	5	TT	(6)	-	7.0
		1135	15	TT	35	0.52 ± 0.09	9.2
		1117	15	TT	34	0.49 ± 0.08	8.8
		1055	25	TT	1	0.49	8.5
		1028	40	TT	3	0.65 ± 0.15	5.3
		0939	60-0	BON	9	0.60 ± 0.26	8.1
		1217	60-0	TT	23	0.47 ± 0.10	7.3
V14	5 Jun	1817	15	TT	47	0.46 ± 0.10	8.6
		1644	40	TT	(3)	-	5.4
		1612	60	TT	(1)	-	4.7
V15	5 Jun	2355	15	TT	19	0.53 ± 0.10	7.7
		2333	25	TT	25	0.48 ± 0.08	7.7
		2250	60	TT	(1)	-	10.1
		2232	60-0	BON	12	0.51 ± 0.08	8.2
V16	6 Jun	0554	5	TT	6	0.45 ± 0.07	7.9
		0532	15	TT	31	0.51 ± 0.09	8.9
		0507	25	TT	(3)	-	5.5
		0441	40	TT	(1)	-	6.0
		0618	60-0	TT	30	0.50 ± 0.06	9.0
		0339	60-0	BON	12	0.49 ± 0.12	6.4
		0637	60-0	BON	8	0.48 ± 0.13	7.6

1/ TT = Tucker trawl, BON = bongo net
2/ Parentheses denote fish that were examined and found to have unreadable otoliths.