

THE NUMBERS AND DISTRIBUTION OF WALLEYE  
POLLOCK EGGS AND LARVAE IN SOUTHEASTERN  
BERING SEA

by

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## CONTENTS

INTRODUCTION . . . . .	.57
METHOD AND DATA. \ . . . .	.57
RESULTS. . . . \ . . . . \ . . . . \ . . . .	.63
DISCUSSION . . \ . \ . \ . \ . \ . \ .	.65
CONCLUSIONS. . . \ \ . . . \ \ \ \ .	.66
REFERENCES . \ \ . . . \ . \ \ \ \ .	.67
APPENDIX I . . \ . . \ . \ . \ \ .	.81
APPENDIX II . \ \ \ \ \ . . \ . . \ .	.85
APPENDIX III \ \ \ \ \ . . \ \ \ . .	.87

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This report does not constitute a publication and is for information only.  
All data herein are to be considered provisional.

## TABLES

Table 1. The total numbers of eggs (E+11) and larvae (E+11) present in each sub area during each survey. Larval data are in parentheses.

Table 2. Summary table of egg for U.S. scientists' data.

Table 3. The number of eggs present **in spawning** areas from Soviet survey.

## FIGURES

- Figure 1. Research area in southeastern Bering Sea. The size of each subarea is  $0.5^{\circ}$  latitude by  $1^{\circ}$  longitude. 100 m isobath is included.
- Figure 2. Spatial distribution of pollock eggs and larvae. The three subareas with the greatest densities during each survey are indicated. 100 m isobath is included. (A) Eggs (B) Larvae.
- Figure 3. The relative abundance of pollock egg with time. (A) Based on U.S. scientists' data. (B) Based on Moiseev and Bulatov (1978) and Kendall (pers. comm.).

## INTRODUCTION

Our interest and knowledge in walleye **pollock**, *Theragra chalcogramma*, the most abundant commercial fish in North Pacific Ocean has increased through last decade. At the same time, interest in petroleum development in the area has increased. Our present research is prepared to exam some possible effects of oil pollution on fish in southeastern Bering Sea. In walleye **pollock** the **planktonic** egg and larva is the life history stage that would most likely be **severly** impacted by oil pollution. Therefore we have examined **the** amount of spawning and its distribution in time and space in southeastern Bering Sea.

The main spawning ground of walleye **pollock** is located between Unimak Pass and the **Probilof** Islands. Spawning occurs during a fairly long season, primarily in spring.

## METHOD AND DATA

The spatial and temporal distribution of spawning is inferred from the distribution of the **planktonic** eggs. For the spatial scales used in our analysis, and considering the generally low velocity of currents in the southeastern Bering Sea, differences in the spatial distribution of eggs and of spawning cannot be detected. The eggs require between 2-3 weeks to hatch at the temperatures at which they occur. Thus, the temporal distribution of spawning would be displaced 2-3 weeks earlier than the occurrence of eggs. Considering egg mortality the actual displacement would probably be less.

We reviewed information about walleye **pollock** egg and larval distribution from various **ichthyoplankton** surveys, and collected available data from them.

Our area of concern, the southeastern Bering Sea, has been examined by research teams from several different countries (U.S., U.S.S.R., Japan). However, because each team had different sampling strategies as well as different sampling gear, comparing their data is very difficult and dangerous. Therefore, we chose U.S. scientists' **ichthyoplankton** surveys (**Waldron**, 1978; **Waldron and Vinter**, 1978; and **Walline**, 1981) that used same gear and same sampling methods for surveys during 1977, 1978, and 1979.

From 1977 to 1979, the sea surface temperatures near **Pribilof** Islands were warmer than the average (**Niebauer**, 1980) while from 1973 to 1976 they were colder than the average. However, the average sea surface temperatures during March, which is assumed to be important time for **pollock** spawning, were nearly the same from 1977 to 1979. Therefore we feel it is reasonable to assume that there was no difference in **pollock** spawning pattern among the years 1977-79 (the temperature during April 1977 was **below** normal, although it was above normal in March and May).

In order to investigate the pattern of temporal and spatial spawning and egg and larval distribution, we divided our research area to 37 rectangles of 0.5 degree of latitude by 1 degree of longitude each (Fig. 1). We calculated the areas of the small rectangles based on **Lafond** (1957). For better temporal resolution, we divided the 1977 cruise into four surveys. We then arranged the U.S. ichthyoplankton surveys in seasonal sequence and assigned them Roman numbers as follows:

- Survey I ; March 10-26, 1978; Waldron (1978)
- Survey II : April 16-22, 1977; Waldron and Vinter (1978)
- Survey III ; April 23-27, 1977; Waldron and Vinter (1978)
- Survey IV ; May 3-9, 1977; Waldron and Vinter (1978)
- Survey V ; May 10-15, 1977; Waldron and Vinter (1978)
- Survey VI ; June 1-23, 1979; Walline (1981)

As mentioned above, we divided our research area to 37 subareas. The total number of eggs or larvae in a subarea was calculated by multiplying their average number per square meter by the area of the subarea in square meters. Appendix III includes results of eggs and larval abundance calculations for each subarea.

To arrive at the temporal distribution of spawning, we assumed uniform spawning activity within the total sampling area. Therefore the total amount of eggs present in the entire **sampling** area during each specific survey was calculated by multiplying the area occupied by each station by sum of numbers of eggs present per square meter through all stations.

Generally spawning activity with time approximates a normal distribution. Therefore we could make a normal distribution curve of pollock egg abundance with time from a polynomial equation (Tanaka, 1962) based on the above data sources:

The normal distribution curve is

$$f(x) = \frac{N}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

where N = total number of individuals,  
 S = standard deviation of distribution  
 m = mean of distribution,  
 X = abscissa, Julian day,  
 $\pi = 3.14159$

Taking natural logarithms, we get

$$\ln (f(X)) = \left( \ln \frac{N}{S\sqrt{2\pi}} - \frac{m^2}{2S^2} \right) + \left( \frac{m}{S^2} \right) x - \frac{1}{2S^2} x^2$$

This is the parabola, also called the second degree polynomial which has form of  $Y=A + BX + CX^2$ . Because we can get the values of the constants (A, B, and C) by use of a computer, N, m, and S can be calculated:

$$A = \ln \left( \frac{N}{S\sqrt{2\pi}} \right) - \left( \frac{m^2}{2S^2} \right)$$

$$B = \frac{m}{S^2}$$

$$C = - \frac{1}{2S^2}$$

For comparison with our study based on U.S. data, we made another normal distribution curve of pollock egg abundance with time from Moiseev and Bulatov's (1979) data. Because Moiseev and Bulatov (1979) did not include information about egg production during June, we used a digitizer to calculate egg production during June from Kendall (NWAF, unpublished graph which was based on Bulatov (1979)).

Based on U.S. scientists' ichthyoplankton survey data, total egg production can be estimated as in Houde (1977), assuming there were no

significant differences of spawning pattern during 1977-79, i.e., we combined data by month ignoring the year of the survey.

$$N = \sum (N_i \cdot D_i / a)$$

where N is the total eggs spawned during one spawning season,

$N_i$  is the number of eggs present in survey i

$D_i$  is the duration of survey i

a is egg hatching time

Fecundity and age composition data of **pollock** enable us to make an egg production estimation.

There are several data sources for age composition, fish fecundity-length or weight relationship, and von **Bertalanffy** parameters. After considering all of the data sources, we used data of Smith (1978), Shew (1978), **Niggoi** (1982), and **Niggoi** (1982), respectively because they appeared most reasonable.

In order to calculate the total biomass of eggs spawned, we used egg **density** data from **Kanoh** (1954) and egg diameter data from **Nishiyama and Haryu** (1981).

In general, fecundity of fish is expressed by

$$\text{Fecundity} = A \cdot L^B \quad (1)$$

where A and B are constants, and L is the **length** of fish.

$$\text{Fecundity} = E \cdot W^F \quad (2)$$

where E and F are constants, and W is the weight of fish.

And weight of fish is

$$W = C \cdot L^D \quad (3)$$

where C and D are constants.

Because the length and weight of fish is the function of time, we can express them with time from von Bertalanffy equation;

$$L_t = L_\infty(1 - e^{-K(t-t_0)}) \quad (4)$$

$$w(t) = W_\infty(1 - e^{-K(t-t_0)})^D \quad (5)$$

where  $L_t$  and  $W_t$  = the length and weight at age t

$L_\infty$  and  $W_\infty$  = the asymptotic value of length and weight

K = a relative growth completion rate

$t_0$  = a hypothetical age of zero size

d = a dimensionless exponent reflecting absolute growth rate.

If we combine (1) and (4), and (2), (3) and (5) with each other, we get two fecundity equations with time as follow:

$$\text{Formula 1 : Fecundity (t) = } A \cdot L_\infty(1 - e^{-K(t-t_0)})^B$$

$$\text{Formula II: Fecundity (t) = } E \left( W_{\infty} (1 - e^{-K(t-t_0)})^D \right) F$$

From these we can get the total numbers of egg produced by multiplying fecundity by the total number of females spawning;

$$N = \sum (F_t \cdot N_t)$$

where N is the total number of eggs spawned

$F_t$  is the fecundity of age t fish

$N_t$  is the number of fish at age t.

## RESULTS

As mentioned before, we divided our research area to 37 subareas and calculated the number of eggs and **larvae** present in each area during each survey (Table 1 and Fig. 2). It appears that spawning is active on upper slope area during March, it moves to middle and outer shelf during April, and moves to northwestward later in the spawning season. Roughly speaking, spawning is active at around the 100 m isobath in the southeastern **Bering Sea** although spawning activity probably depends on several **abiotic** factors in addition to depth. The larval distribution in Fig. 2 shows seaward movement of larvae after hatching. This pattern of larval distribution was also observed by **Serobaba** (1974).

After the numbers of egg present at each station during each survey were calculated (Appendix I), the total number of eggs present in our research area

during each survey was calculated (Table 2). Also egg numbers present in eastern Bering Sea from Moiseev and Bulatov (1979) and Kendall (NWAFC, pers. comm.) during 1978 spawning season were calculated (Table 3).

When we assumed that the spawning started on the middle of February, the normal distribution based on the above data indicates that 104.4th Julian day (14 April) is the peak of spawning with a standard deviation of 13.8 days (Fig. 3:  $F(X) = 27.08e^{-\frac{(X-104.41)^2}{382.16}}$ ). Also under the same assumption, the result derived from Moiseev and Bulatov (1979) and Kendall (pers. comm.) shows 107.9th Julian day (18 April) as the peak of spawning and 26 days as one standard deviation (Fig. 3:  $F(X) = 15.56e^{-\frac{(X-107.94)^2}{1428.82}}$ ), although smaller egg production was indicated by the Soviets' data than by U.S. scientists'. These results are not significantly different from others which indicate that along the slope and outer shelf the peak spawning occurs in March and April (Lynde, 1983).

Larvae were found beginning in the middle of March in southeastern Bering Sea. Table 1 shows that the maximum larval abundance occurred at around second survey, which was conducted just after peak spawning, and that the number of larvae decreases with time. Walline (1983) calculated the egg hatching dates for pollock from 1979 survey data; hatching dates were distributed from 1 April to 15 July; the hatch was most pronounced during the last 2 weeks in April and the last 2 weeks in May.

Based on Table 2, (ichthyoplankton survey data), the total number of pollock eggs produced during the spawning season in southeastern Bering Sea was estimated. If development time from spawning to hatching is assumed to be

17.3 days which corresponds to duration of the **pollock** egg stage in 4°C seawater (Richard Bates, **NWAF** pers. **comm.**), the total number becomes 3.6918 **E+13 eggs** (282.7 **eggs/m<sup>2</sup>**) (see Appendix II).

Also we calculated **pollock** egg production by knowing the fecundity-age composition relationship of the adult population, although more research is needed to estimate the parameters more precisely for **pollock** in the eastern Bering Sea. For calculations of number of eggs produced the following constants were used: von **Bertalanffy** constants of **K=0.209**,  $t_0 = -0.315$  year,  $L_{\infty} = 65.01$  cm (**Niggol**, 1981); **Shew's** fecundity-length relationship data (1978); and **Smith's** age composition data (1981). If we multiply fecundity by number of females at each age, the calculation resulted in 6.17 " **E+13** eggs in 159,100 km<sup>2</sup> which equals a density of 387.95 eggs/m<sup>2</sup>. For transforming this number to total weight of eggs produced, we multiplied the total number of eggs by the average density of egg (**Kanoh**, 1954), 1.021, and mean egg volume of 0.0027 cm<sup>3</sup> which came from **Nishiyama and Haryu** (1981). The total weight of eggs produced in the spawning area of 159,100 km<sup>2</sup> is about 170,000 mt in one spawning season.

## DISCUSSION

The egg density derived from fecundity data (387.95 **eggs/m<sup>2</sup>**) is higher than that of the ichthyoplankton surveys (282.7 **eggs/m<sup>2</sup>**) and that of **Serobaba** (1968) (293.44 **eggs/m<sup>2</sup>**). This indicates that spawning probably occurs outside the areas sampled during these **ichthyoplankton** surveys. Also matchability of eggs may be less than 100% with the methods used in these surveys.

In performing this study, the biggest problem is in data variation. Because small numbers of **ichthyoplankton** surveys have been conducted in Bering Sea and data collecting methods have varied, we needed to use many assumptions, which should be reconsidered when more data becomes available. Also the basic biology of **pollock** is not well understood. We do not know the exact spawning time of **pollock** in southeastern Bering Sea nor do we understand the variation in size of **pollock** eggs, which influences our estimation of **pollock** egg biomass. In order to understand **pollock** in Bering Sea more exactly, we need to increase research activities to study their biology in relation to oceanographic conditions.

#### CONCLUSIONS

Spawning occurs over a large area of the southeastern Bering Sea, mainly between the **Pribilof** Islands and Unimak Pass, between the 100-200 m **isobaths**. Present data are insufficient to resolve the pattern of spawning and larval distribution adequately. The total spawning area was probably not sampled during the surveys considered in this report.

Spawning peaks on about Julian day 104-108 (14-18 April) with a standard deviation of between 14 and 26 days, based on two sets of **ichthyoplankton** surveys. Some spawning occurs from about 15 February through June.

Based on fecundity and size of the adult population,  $6.17 \times 10^{13}$  eggs are produced during the spawning season. Based on **ichthyoplankton** surveys  $3.69 \times 10^{13}$  eggs are produced during the spawning season. The difference between these two estimates may partially be a result of the plankton surveys not covering the entire spawning area. The density of egg spawned based on adult

population parameters was 388 eggs/m<sup>2</sup> while that based on plankton surveys was 283 eggs/m<sup>2</sup>. This difference may be due in part to problems in plankton sampling and egg mortality.

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Table 1.--The total numbers of eggs (**E+11**) and larvae (**E+11**) present in each sub area during each survey. Larval data are in parentheses.

Subarea	Survey					
	I	II	III	IV	v	VI
A(1,1)		0.0000 (0.000)			1.3560 (0.428)	
A(1,2)		0.0381 (0.114)			1.8716 (0.496)	0.0000 (0.000)
A(1,3)						0.0000 (0.024)
A(1,4)						0.0221 (0.092)
A(1,5)						0.1158 (0.719)
A(2,1)						0.0000 (0.000)
A(2,2)			1.0005 (1.221)		0.0867 (0.737)	0.0000 (0.024)
A(2,3)			1.2447 (0.181)		0.8949 (0.291)	0.0000 (0.000)
A(2,4)			0.5220 (0.019)		0.6674 (0.000)	(-).0079 (0.075)
A(2,5)			12.9470 (0.000)	3.7147 (0.000)		
A(3,1)					0.0485 (0.388)	
A(3,2)	0.0193	0.0397 (0.218)			0.0413 (0.496)	0.0000 (0.000)

Subarea	Survey					
	I	II	III	IV	v	VI
A(3,3)	<b>0.0182</b>	0.1532 (0.153)	0.1871 (0.122)	(1.118)	0.4421	<b>0.0000</b> (0.103)
A(3,4)	0.0000	0.1547 (0.000)	0.1793 (0.021)		0.2623 (0.031)	0.0000 (0.123)
A(3,5)	0.0000	0.6378 (0.000)	0.3298 (0.000)	0.7144 (0.675)		
A(3,6)		25.8220 (0.000)		0.7017 (0.000)		
A(4,1)	0.1158					
A(4,2)	2.2444	0.0867 (12.113)			<b>0.0213</b> (0.255)	<b>0.0000</b> (0.000)
A(4,3)	0.0550	0.1239 (0.137)	0.3672 (0.516)	<b>0.1437</b> (1.265)	<b>0.2008</b> (3.414)	<b>0.0000</b> (0.015)
A(4,4)	0.0000	0.0186 (0.008)	0.0102 (0.051)	0.1648 (0.991)		
A(4,5)	0.0309	1.3577 (0.071)	3.9712 (0.135)	2.2624 (0.822)		
A(4,6)	0.0000	2.5091 (0.000)	11.9090 (0.000)	7.6239 (0.590)		
A(4,7)				0.4143 (0.000)		
A(5,1)	0.0000					(0.025)

Subarea	Survey					
	I	II	111	IV	v	VI
A(5,2)	0.2358	0.5192 (16.817)		0.0677 (0.293)		0.0000 (0.000)
A(5,3)	34.3490	0.0160 (1.495)	0.0483 (6.884)	0.0990 (2.299)		0.0000 (0.012)
A(5,4)		0.1257 (3.839)	0.5852 (3.162)	0.4044 (0.929)		0.0000
A(5,5)	0.0184	0.6430 (0.047)	0.6932 (0.158)	0.6790 (0.980)		
A(5,6)		0.0559 (0.000)	0.0000 (0.000)	0.1966		
A(6,1)						0.0000
A(6,2)		0.1382 (0.737)	0.1100 (2.134)	0.2351 (2.962)	0.0882 (0.639)	
A(6,3)	1.0763	0.0223 (2.053)	0.0206 (5.615)		0.0758 (0.162)	
A(6,4)	0.0000	0.4393 (4.675)	5.3085 (2.628)	0.7404 (0.912)	0.0468 (0.937)	
A(6,5)	0.0000	2.2694 (5.266)	13.9810 (8.063)	2.5505 (0.548)		
A(7,1)				0.2068 (3.392)		
A(7,2)			0.2745 (5.108)	0.1067 (1.328)		

Subarea	Survey					
	I	II	III	IV	V	VI
A(7,3)		0.4877 (20.950)			0.0843 (0.139)	
Total (E+11)	38.163	35.620 (68.686)	53.689 (36.018)	21.027 (19.104)	6.188 (8.413)	<b>0.146</b> (1.212)
Mean (E+11)	2.245	1.781 (3.122)	2.557 (1.801)	1.168 (1.061)	0.413 (0.601)	0.009 (0.076)
No. animals/ survey (E+11)	87.55	69.46 (109.27)	99.71 (63.03)	45.56 (37.14)	16.09 (21.04)	0.34 (2.65)

**Table 2. Summary table of egg for U. S. scientists' data.**

Survey duration	Mid-day of survey (Julian day (X))	No. of station sampled	Total eggs during survey (E+11 eggs)	Number of survey days	No. of eggs sampled/day (E+11)
Feb. 14	45			1	0.001
Mar. 10-16	71	21	70.100	7	10.010
Apr. 16-22	108	35	119.832	7	17.119
Apr. 23-27	114	31	90.430	5	18.086
May 3-9	125	<b>28</b>	40.505	7	5.786
May 10-15	131.5	17	14.564	6	2.427
June 1-23	162	39	0.170	22	0.008

Table 3. The number of eggs present in spawning areas from Soviet survey.

Survey duration	Mid-day of survey (Julian day (X))	Total eggs during survey (E+8)	No. of eggs sampled per day (E+8)
April 10 - May 3	110.5	294.7	12.28
May 10-20	134.0	151.0	13.73
June 1-30	166.0	40.2	1.34

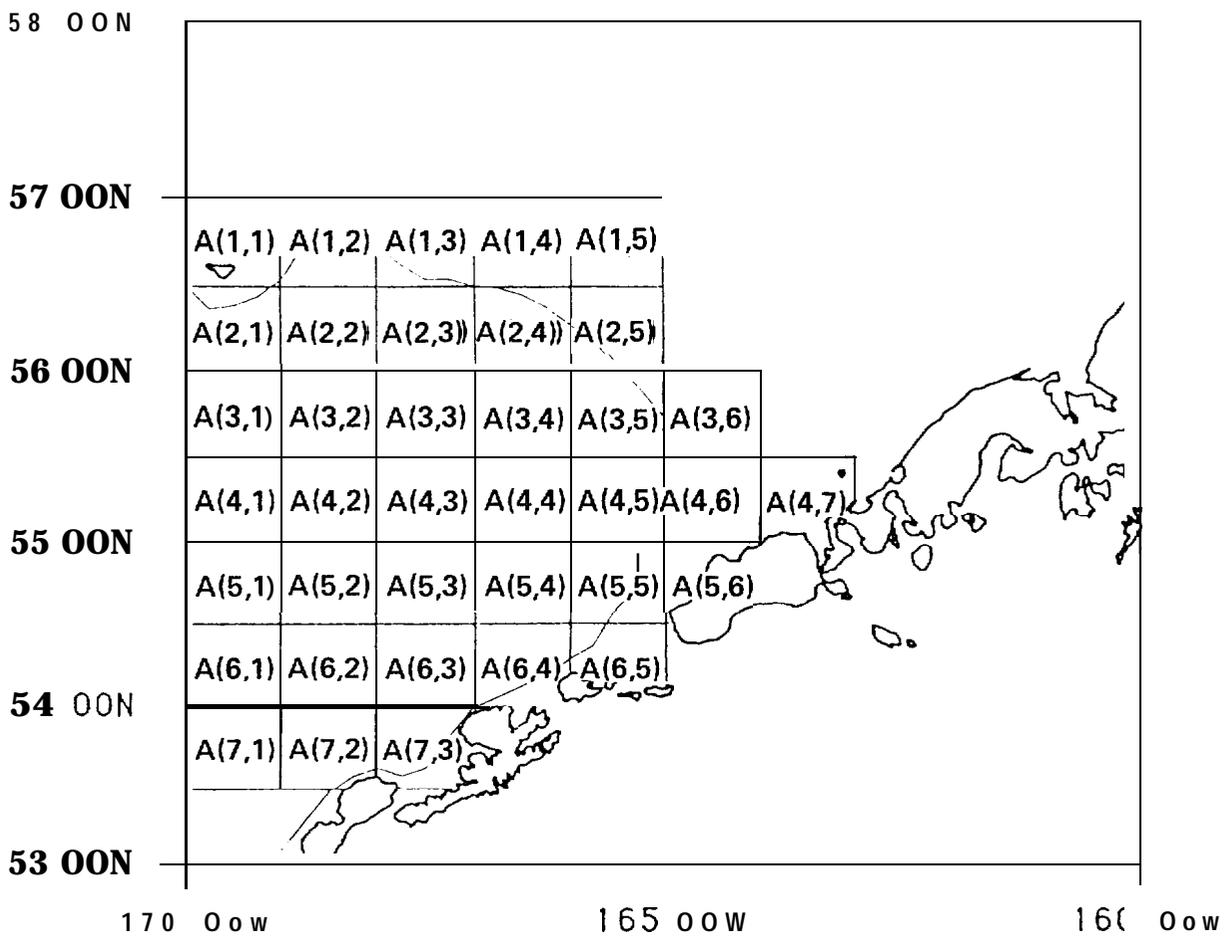


Figure 1. Research area in southeastern Bering Sea. The size of each subarea is 0.5° latitude by 1° longitude. 100 m isobath is included.

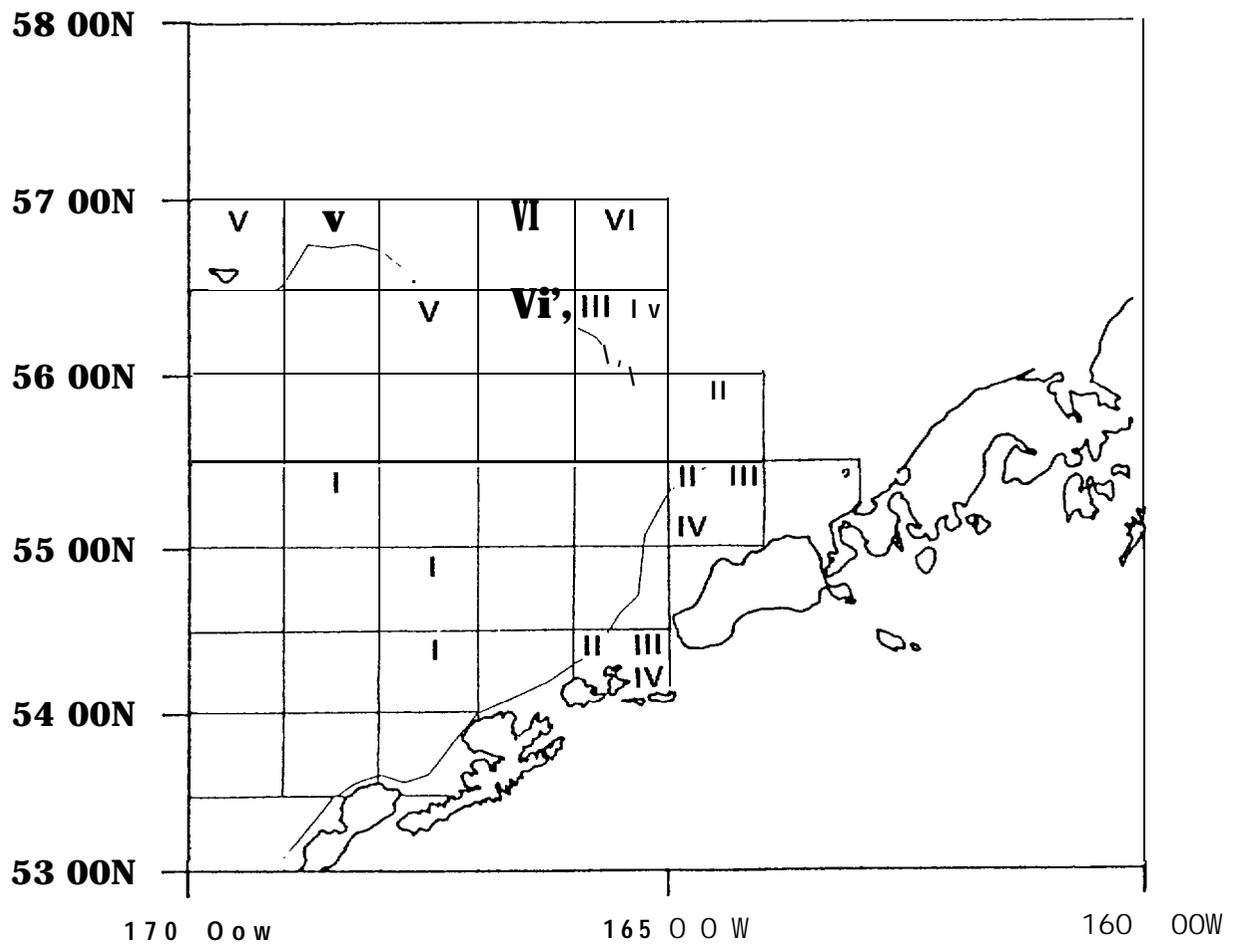


Figure 2. Spatial distribution of pollock eggs and larvae. The three subareas with the greatest densities during each survey are indicated. 100 m isobath is included. (A) Eggs,

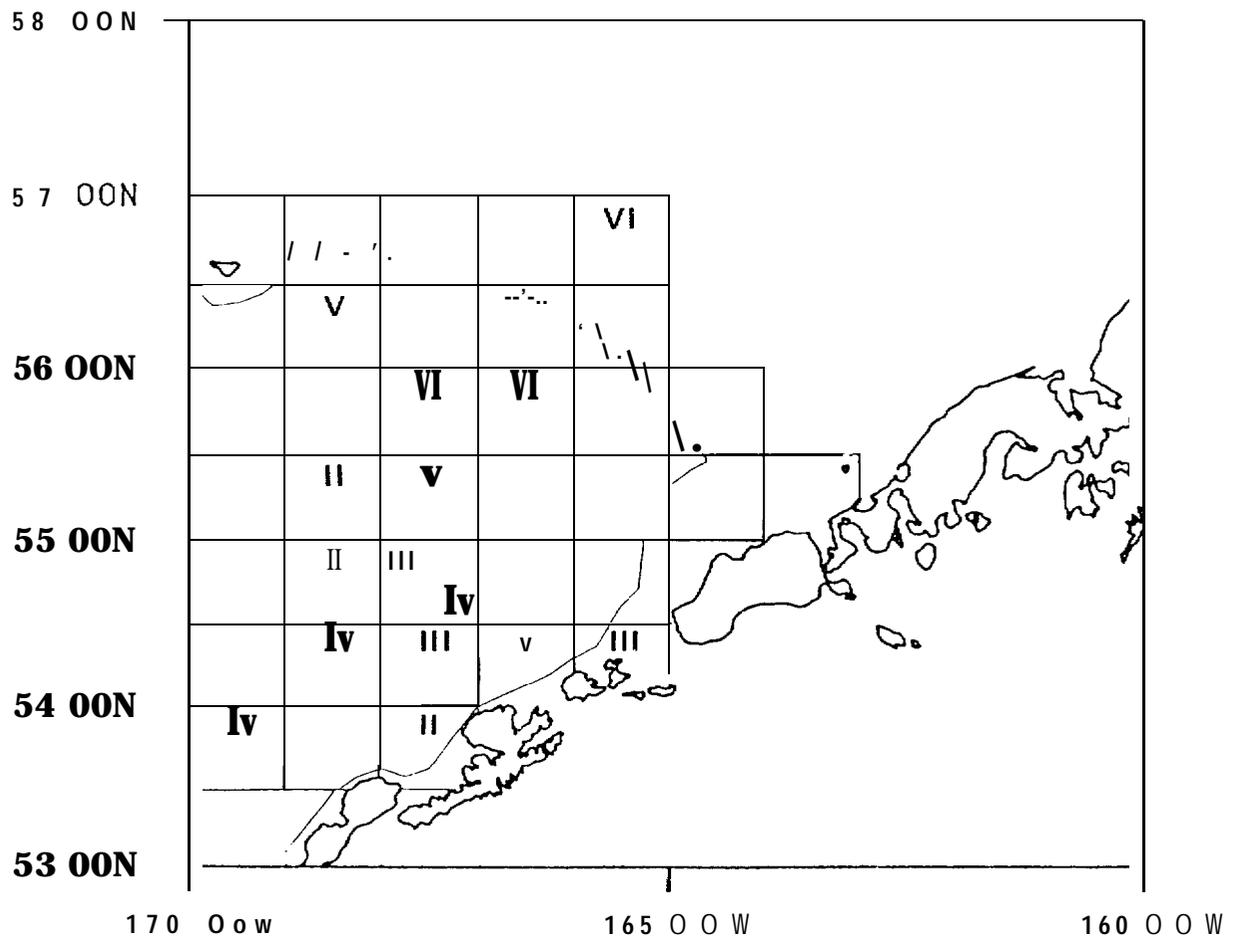
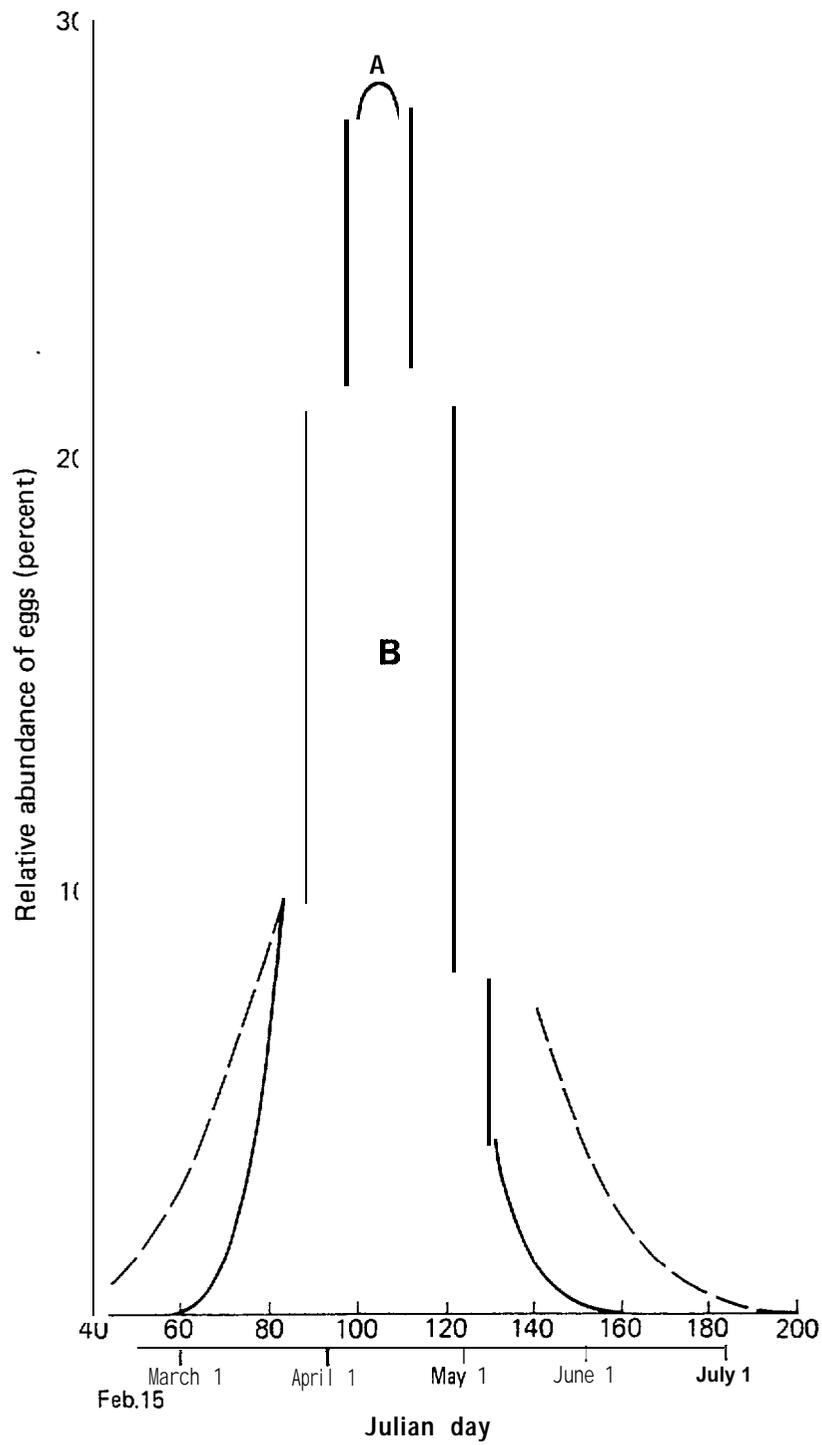


Figure 2. Spatial distribution of pollock eggs and larvae. The three subareas with the greatest densities during each survey are indicated. 100 m isobath is included. (B) Larvae.



**Figure 3.** The relative abundance of pollock egg with time. (A) Based on U. S. scientists' data. (B) Based on Moiseev and Bulatov (1978) and Kendall (pers. comm.).

Appendix I: The number of eggs present at each station during each survey.

1) The total number of eggs present at each station during March 10-16, 1978.  
(Survey I)

Station	No. of eggs sampled during survey	SHF	No. of eggs/m <sup>2</sup>
16	203	4.252	86.3156
17	5	5.379	2.6895
18	11	5.980	6.5780
19	<b>1858</b>	<b>5.158</b>	958.3564
20	100	6.340	63.4000
21	<b>6</b>	<b>5.450</b>	3.2700
22	<b>1</b>	<b>5.494</b>	0.5494
23	<b>4</b>	<b>4.876</b>	1.9504
24	<b>1</b>	<b>5.181</b>	0.5181
28	<b>2</b>	5.791	1.1582
29	<b>3</b>	5.817	1.7451
32	<b>1</b>	5.147	0.5147
			Total 1127.0454

SHF (Standard Haul Factor) converts actual catch to numbers beneath 10 m<sup>2</sup> of sea surface.

Total number of egg present in area of concern = (130613 .6"1000000/21)"1127 .045  
= **7.0099•E+12**

2) The number of eggs present at each station during April 16-May 15, 1977. \*

Station	Survey II		Survey III		Survey IV		Survey V	
	SHF	No. of eggs total /m <sup>2</sup>	SHF	No. of eggs total /m <sup>2</sup>	SHF	No. of eggs total /m <sup>2</sup>	SHF	No. of eggs total /m <sup>2</sup>
1	6.55	30 19.635	6.69	427 285.834	6.62	58 38.367		
2	5.73	8 4.584	6.19	11 6.810	6.12	4 2.448	6.46	2 1.219
3	4.99	1 0.499	6.53	1 0.653	5.42	6 3.253		
4	3.92	1 0.392	6.80	3 2.041	5.68	4 2.272		
5	3.04	11 3.347	6.77	6 4.059			5.67	10 5.672
6	4.06	9 3.653	5.96	28 16.685	4.06	10 4.059		
7	5.53	2 1.106	6.54	24 15.698	4.86	19 9.234		
8	5.91	10 5.910	6.28	27 16.956	5.80	23 13.333	Bongo tow aborted	
9	4.73	131 62.553	5.68	678 385.375	5.81	121 70.301		
10	4.77	12 5.725	5.49	9 4.945	4.78	55 26.301		
11	5.20	58 30.154	5.84	58 33.855	5.04	23 11.587		
12	4.34	.	6.38	-	4.81	15 7.221		
13	5.25	2 1.050	5.78	1 0.578	4.18	5 2.091		
14	5.51	3 1.650	5.96	4 2.385			5.75	16 9.197
15	5.04	14 7.062	5.50	15 8.252			5.50	29 15.936
16	6.00	7 4.202	5.59	14 7.829			5.99	22 13.174
17	5.11	9 4.594	5.91	4 2.363	5.79	3 1.736		
18	5.00	6 2.998	5.87	.	5.15	4 2.059		
19	5.38	137 73.7136	6.03	372 224.353	5.54	227 125.758		
20	5.20	3 1.561	5.73	-	5.49	10 5.485		
21	4.34	2 0.868	4.54	121 54.922	4.52			
22	5.73	246 140.884	5.50	1123 617.875	4.90	879 430.711		
23	5.82	36 20.941	5.58	25 13.958	5.18	68 35.251		
24	6.38	24 15.314	5.99	8 4.790	5.36	10 5.360		
25	5.98	1741 1041.466			5.08	16 8.120		
26	6.96	682 474.536			5.12	62 31.769		
27	Bongo tow shorted				4.07	54 21.967		
39	5.11	2 1.120					4.70	117 54.943
40	4.86	-					5.24	76 39.809
49	6.35	6 3.808			6.48	10 6.479	6.08	4 2.430
50	6.99	19 13.283					7.65	3 2.296
51	6.15	1 0.615					6.85	3 2.055
57	6.30	23 14.485			6.29	3 1.888		
53	6.12	4 2.448					6.01	1 0.601
54	5.64	2 1.128					5.87	2 1.114
55	Bongo tow aborted						6.89	2 1.379
58			5.87	50 29.370			6.37	4 2.546
59			5.89	62 36.537			6.11	43 26.269
60			5.68	27 15.323			6.32	31 19.592
61			5.24	726 380.061	5.65	193 109.045		
62					4.19	142 59.427		
64			6.48	1 0.648			7.07	3 2.122
65			6.06	5 3.032	5.81	5 2.906		
66			6.23	12 7.476	5.63	10 5.633		
	<b>Total</b>	<b>1965.277</b>		<b>2182.660</b>		<b>984.634</b>		<b>200.486</b>

82

Total number of eggs present in area of concern: subarea 1: Station No. 1-24  
subarea 2; Station No. 25-66

Survey II

subarea 1:  $(4.404 \text{ E}+10/24) \cdot (19.6350+4.5840+ \dots +15.3144) = 7.5673 \cdot \text{E}+11$   
+) subarea 2:  $(5.166 \text{ E}+10/10) \cdot (1041.4662+474.5356+ \dots +1.1282) = \frac{80.222 \cdot \text{E}+11}{9 \cdot \text{E}+11}$

Survey III

subarea 1:  $(4.404 \text{ E}+10/24) \cdot (285.8338+6.8101+ \dots +4.7896) = 31.382 \cdot \text{E}+11$   
+) subarea 2:  $(5.166 \text{ E}+10/8) \cdot (29.370+36.537+ \dots +7.476) = \frac{34.866 \cdot \text{E}+11}{8 \cdot \text{E}+11}$

Survey IV

subarea 1:  $(4.404 \text{ E}+10/20) \cdot (38.367+2.448+ \dots +5.360) = 17.546 \cdot \text{E}+11$   
+) subarea 2:  $(5.166 \text{ E}+10/8) \cdot (8.120+31.769+ \dots +5.633) = \frac{12.128 \cdot \text{E}+11}{9.674 \cdot \text{E}+11}$

Survey V

subarea 1:  $(4.404 \text{ E}+10/5) \cdot (1.2912 +5.672 + \dots + 13.174) = 3.9873 \cdot \text{E}+11$   
+) subarea 2:  $(5.166 \text{ E}+10/12) \cdot (54.943+39.809+ \dots +2.122) = \frac{6.6821 \cdot \text{E}+11}{10.6694 \cdot \text{E}+11}$

\*They mentioned that the total area of subarea 1 and 2 is 95700 km<sup>2</sup>. Because we assumed equal production rate outside this area, we can correct that number to 130613.6 km<sup>2</sup> by multiplying 1.365 to total egg number present in subarea 1 and 2;

	Survey			
	II	III	IV	V
Amount of egg present (E+11)	119.832	90.430	40.505	14.564

3) Total number of eggs present at each station during June 1-23, 1979 (Survey VI).

Station	No. of eggs/m <sup>2</sup>
V01-8	0.7
S 46A	1.3
S 12A	3.4
Total	= 5.4

Total number of egg present in area of concern =  $(130613.6 \cdot 1000000/40) \cdot 5.4 = 1.763 \cdot \text{E}+10$

**Appendix II: The estimation of total egg number produced.**

Survey (i)	$N_i$ (E+11) eggs	$D_i$ days
I	70.10	34.5
II	119.83	22.5
III	9(-).43	7.5
IV	40.51	9.5
v	14.56	14.0
VI	0.17	31.0

$$\begin{aligned}
 N &= \sum (N_i * D_i / a) \\
 &= (6386.805 / 17.3) E+11 \\
 &= 369.18 * E+11 \text{ (eggs)}
 \end{aligned}$$

Appendix III: Total number of pollock eggs and larvae in subarea A(i, j) during specific survey.

EGGS

Subarea	No. of times sampled	No. of times egg caught	Survey (station number)	No. of eggs/m <sup>2</sup>	Total No. of eggs present /subarea
A(1,1)	2	1	II (40) v (40)	0 39.8088	0 1.3560 E+11
A(1,2)	5	3	II (39) v (39) VI (S47A, S48A)	1.1196 54.9432 0	3.8140 E+9 1.8716 E+11 0
A(1,3)	1	1	VI (S45A)	0	0
A(1,4)	2	1	VI (S40A, S46A)	1.3000	2.2142 E+9
A(1,5)	1	1	VI (S12A)	3.4000	1.1582 E+10
A(2,1)	2	2	VI (S50A, S53A)	0	0
A(2,2)	4	2	III (58) V (58) VI (S41A, S44A)	29.3700 2.5460 0	1.0005 E+11 8.6732 E+9 0
A(2,3)	4	2	III (59) v (59) VI (S38A, S39A)	36.5366 26.2687 0	1.2447 E+11 8.9487 E+10 0
A(2,4)	5	3	III (60) V (60) VII (V01-8, S33A, S34A)	15.3225 19.5920 0.2333	5.2198 E+10 6.6742 E+10 0.7949 E+9
A(2,5)	2	2	III (61) IV (61)	380.0610 109.0450	1.2947 E+12 3.7147 E+11
A(3,1)	2	1	II (55) v (55)	Bongo tow aborted 1.3788	4.8509 E+9
A(3,2)	5	3	I (22) 11 (54) v (54) VI (S42A, S43A)	0.5494 1.1282 1.1740 0	1.9329 E+9 3.9692 E+9 4.1304 E+9 0

Subs rea	No. of times sampled	No. of times egg caught	Survey (station number)	No. of eggs/m <sup>2</sup>	Total No. of eggs present /subarea
A(3,3)	11	7	I (24)	0.5181	1.8228 E+9
			11 (14, 15)	4.3557	1.5324 E+10
			III (14, 15)	5.3184	1.8711 E+10
			IV (14, 15)	12.5662	4.4210 E+10
			VI (S08A, S08B, S29A, S35A)	0	0
A(3,4)	11	6	I (25)	0	0
			II (16,17)	4.3979	1.5473 E+10
			III (16, 17)	5.0958	1.7928 E+10
			V (16, 17)	7.4546	2.6227 E+10
			VI (S09A, S30A, S31A, S32A)	0	0
A(3,5)	7	6	I (26)	0	0
			II (23, 24)	18.1278	6.3777 E+10
			111 (23, 24)	9.3736	3.2978 E+10
			IV (23, 24)	20.3056	7.1439 E+10
A(3,6)	4	4	II (25, 26)	758.0009	2.5822 E+12
			IV (25, 26)	19.9444	7.0168 E+10
A(4,1)	1	1	I (21)	3.2700	1.1576 E+10
A(4,2)	4	3	I (20)	63.4000	2.2444 E+11
			11 (53)	2.4484	8.6676 E+9
			v (53)	0.6014	2.1290 E+99
			VI (S13A)	0	0
A(4,3)	13	8	I (23, 28)	1.5543	5.5024 E+9
			II (5, 6)	3.5002	1.2391 E+10
			III (5, 6)	10.3721	3.6719 E+10
			IV (6)	4.0590	1.4369 E+10
			v (5)	5.6720	2.0080 E+10
			VI (S06A, S07A, S28A, S36A, S37A)	0	0
A(4,4)	7	4	I (27)	0	0
			II (12, 13)	0.5251	1.8589 E+9
			111 (12, 13)	0.2890	1.0231 E+9
			IV (12, 13)	4.6560	1.6483 E+10
A(4,5)	8	6	I (29, 30)	0.8726	3.0890 E+9
			II (18, 19)	38.3521	1.3577 E+11

Subarea	No. of t i m e s s a m p l e d	No. of t i m e s e g g c a u g h t	Survey (station number)	No. of e g g s / m <sup>2</sup>	Total No. of e g g s p r e s e n t /subarea
			III (18, 19)	112.1766	3.9712 E+11
			IV (18, 19)	63.9084	2.2624 E+11
A(4,6)	7	5	I (31)	0	0
			II (21, 22)	70.8759	2.5091 E+11
			III (21, 22)	336.3983	1,1909 E+12
			Iv (21, 22)	215.3550	7.6239 E+11
A(4,7)	3	2	II (27)	Bongo tow aborted	
			IV (27)	21.9672	7.7767 E+10
A(5,1)	1	0	VI (S14A)	0	0
A(5,2)	6	3	I (18)	6.5780	2.3577 E+10
			II (52)	14.4854	5.1918 E+10
			IV (52)	1.8882	6.7676 E+9
			VI (S04A, S05A, S27A)	0	0
A(5,3)	10	7	I (19)	958.3564	3.4349 E+12
			II (3, 4)	0.4456	1.5971 E+9
			III (3, 4)	1.3471	4.8282 E+9
			Iv (3, 4)	2.7623	9.9005 E+9
			VI (S01A, S02A, S03A)	0	0
A(5,4)	8	6	II (7, 8)	3.5078	1.2572 E+10
			III (7, 8)	16.3272	5.8519 E+10
			IV (7, 8)	11.2836	4.0442 E+10
			V (8)	Bongo tow aborted	
			VI (S14A)	0	0
A(5,5)	7	7	I (32)	0.5147	1.8448 E+9
			II (10, 11)	17.9397	6.4298 E+10
			III (10, 11)	19.3996	6.9317 E+10
			Iv(l(-), 11)	18.9442	6.7899 E+10
A(5,6)	3	2	II (20)	1.5609	5.5945 E+9
			III (20)	0	0
			IV (20)	55.4850	1.9659 E+10
A(6,1)	1	0	VI (S26A)	0	0

Subarea	No. of times sampled	No. of times egg caught	Survey (station number)	No. of eggs/m <sup>2</sup>	Total No. of eggs present /subarea
A(6,2)	4	4	II (49)	3.8082	1.3816 E+10
			III (65)	3.0320	1.1000 E+10
			IV (49)	6.4790	2.3506 E+10
			v (49)	2.4304	8.8174 E+9
A(6,3)	7	6	I (15, 16, 17)	29.6684	1.0763 E+11
			II (51)	0.6151	2.2316 E+9
			III (64)	0.6476	2.2061 E+9
			V (51, 64)	2.0885	7.5770 E+9
A(6,4)	8	7	I (12)	0	0
			II (1, 2)	12.1095	4.3933 E+10
			III (1, 2)	146.3220	5.3085 E+11
			IV (1, 2)	20.4077	7.4038 E+10
			v (2)	1.2912	4.6844 E+9
A(6,5)	4		I (13)	0	0
			II (9)	62.5525	2.2694 E+11
			III (9)	385.3752	1.3981 E+12
			IV (9)	70.3010	2.5505 E+11
A(7,1)	1	1	Iv (66)	5.6330	2.0681 E+10
A(7,2)	2	2	111 (66)	7.4760	2.7447 E+10
			IV (65)	2.9060	1.0669 E+10
A(7,3)	2	2	II (50)	13.2829	4.8767 E+10
			v (50)	2.2962	8.4303 E+9

LARVAE

Subarea	No. of times sampled	No. of times larvae caught	Survey (station number)	No. of larvae/m <sup>2</sup>	Total No. of larvae present (E+10)/subarea
A(1,1)	2	1	II (40)	0	0
			v (40)	12.5712	4.2822
A(1,2)	4	2	11 (39)	3.3588	1.1441
			V(39)	14.5576	4.9588
			V I (S47A,S48A)	0	0

Subarea	No. of times sampled	No. of times larvae caught	Survey (station number)	No. of larvae/m <sup>2</sup>	Total No. of larvae present (E+10)/subarea
A(1,3)	1	1	VI (S45A)	0.7	0.2384
A(1,4)	1	1	VI (S40A)	2.7	0.9197
A(1,5)	1	1	VI (S12A)	21.1	7.1874
A(2,1)	2	0	VI (S50A,S53A)	0	0
A(2,2)	4	4	III (58) V (58) VI (S41A,S44A)	35.8314 21.6410 0.7	12.2060 7.3722 0.2385
A(2,3)	4	2	III (59) v (59) VI (S38A,S39A)	5.3037 8.5526 0	1.8068 2.9135 n
A(2,4)	5	3	III (60) v (60) VI (V01-8, S33A,S34A)	0.5675 0 2.2	0.1933 0 0.7495
A(2,5)	2	0	111 (61) V (61)	0 0	0 0
A(3,1)	1	1	v (55)	11.0304	3.8807
A(3,2)	4	2	II (54) v (54) VI (S42A, S43A)	6.2051 14.0880 0	2.1831 4.9564 0
A(3,3)	9	7	II (14, 15) III (14, 15) IV (14, 15) VI (S08A, S29A, S35A)	4.3557 3.4623 31.7734 2.93	1.5324 1.2181 11.1780 1.0308
A(3,4)	9	5	II (16, 17) III (16, 17) v (16, 17) VI (S09A, S31A, S32A)	0 0.5907 0.8779 3.5	0 0.2079 0.3089 1.2314
A(3,5)	6	1	II (23, 24) III (23, 24) IV (23,-24)"	0 0 19.1808	0 0 6.7482

Subarea	No. of times sampled	No. of times larvae caught	Survey (station number )	No. of larvae/m <sup>2</sup>	Total No. of larvae present (E+10)/subarea
A(3,6)	4	0	II (25, 26) IV (25, 26)	0 0	0 0
A(4,2)	3	2	II (53) V (53) VI (S13A)	342.1639 7.2168 0	121.13 2.5548 0
A(4,3)	11	7	II (5, 6) III (5, 6) IV (6) V (5) VI (S06A, S07A, S28A, S36A, S37A)	3.8558 14.5679 35.7192 96.4240 0.42	1.3650 5.1572 12.6450 34.1350 0.1487
A(4,4)	6		II (12,13) III (12, 13) IV (12, 13)	0.2171 1.4448 28.0048	0.0769 0.5115 9.9141
A(4,5)	6		II (18, 19) III (18, 19) IV (18, 19)	1.9988 3.8155 23.2091	0.7076 1.3507 8.2163
A(4,6)	6		II (21, 22) III (21, 22) IV (21, 22)	0 0 16.66	0 0 5.8979
A(4,7)	1		IV (27)	0	0
A(5,1)	1		VI (S14A)	0.7	0.2509
A(5,2)	5		II (52) IV (52) VI (S04A, S05A, S27A)	469.2010 8.1822 0	168.1700 2.9326 0
A(5,3)	9		II (3, 4) III (3, 4) IV (3, 4) VI (S01A, S02A, S03A)	41.7090 192.0720 64.1443 0.3333	14.9490 68.8410 22.9900 0.1195
A(5,4)	6		II (7, 8) III (7, 8) IV (7, 8)	107.1016 88.2340 25.9135	38.3870 31.6240 9.2878

Subarea	No. of times sampled	No. of times larvae caught	Survey (station number)	No. of larvae/m <sup>2</sup>	Total No. of larvae present (E+10)/subarea
A(5,5)	6	5	II (10, 11)	1.2998	0.4659
			III (10, 11)	4.4124	1.5815
			Iv (10, 11)	27.3296	9.7953
A(5,6)	3	1	11 (20)	0	0
			III (20)	0	0
			Iv (20)	2.7425	0.9830
A(6,2)	4	4	11 (49)	20.3104	7.3685
			III (65)	58.8208	21.3400
			IV (49)	81.6354	29.6170
			v (49)	17.6204	6.3926
A(6,3)	4	4	II (51)	<b>56.5984</b>	20.5340
			III (64)	<b>154.7764</b>	56.1520
			V (51, 64)	<b>4.4744</b>	1.6233
A(6,4)	7	7	II (1, 2)	<b>128.8466</b>	46.7450
			111 (1,2)	<b>72.4442</b>	26.2820
			IV (1, 2)	<b>25.1509</b>	9.1246
			v (2)	<b>25.8240</b>	9.3688
A(6,5)	3	3	II (9)	145.1600	52.6630
			111 (9)	222.2444	80.6290
			Iv (9)	15.1060	5.4804
A(7,1)	1	1	Iv (66)	93.5078	33.9240
A(7,2)	2	2	III (66)	140.7980	51.0810
			IV (65)	36.6156	13.2840
A(7,3)	2	2	II (50)	577.4566	209.5000
			v (50)	3.8270	1.3884