AN ABSTRACT OF THE THESIS OF

Enzo S. Acuña for the degree of Master of Science
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Title: Biology of the Myctophid Fish, Diaphus theta
Eigenmann and Eigenmann 1890, off the Oregon Coast.
Abstract approved: Redacted for privacy
Professor William G. Pearcy

Age and growth of *Diaphus theta* were estimated from analyses of otoliths and length frequency distributions of fish caught in midwater trawls off Oregon. Alternating hyaline and opaque rings in the otoliths of *D. theta* indicated that age groups 0+, I, II, and III were present. Mean standard lengths of 37.7, 50.3 and 63.3 mm were estimated for fish of one, two and three years of age respectively. Back-calculated lengths for these ages were smaller than the lengths estimated by direct otolith measurements. Closely spaced rings, possibly daily growth rings, were detected in otoliths of young fish by scanning electron microscopy.

Two or three distinct modes occurred in length frequency distributions of fish collected from offshore stations. Modal lengths increased with time providing estimates of growth rate that were similar to those derived from otolith aging.

Larvae of *D. theta* were reported in the California

Current between 40°N to 43°20'N in the spring and from 40° N to 46°N during the summer. Largest catches were usually found in offshore waters between 42°N and 44°N. The largest mean length and size range of larvae were found during the summer.

Significant ($P < 0.01$) variations were found between the inshore and offshore abundances of juvenile and adult *D. theta* off Newport. Seasonal variations were evident in the inshore region off Coos Bay and the offshore region off Newport. Age 0 fish were the principal component of the inshore catches in the summer off Coos Bay and the winter off Newport.

Possible effects of physical processes and prey distributions on the seasonal and inshore-offshore trends of abundances of *D. theta* off Oregon are discussed. A negative relationship was found between inshore abundances of *D.theta* and the Bakun upwelling index off Newport.

Biology of the Myctophid Fish, *Diaphus theta* Eigenmann and Eigenmann 1890, off the Oregon Coast

by

Enzo S. Acuña

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Date thesis is presented May 2, 1983

Typed by Enzo S. Acuña

TO KENNA,
CRISTIAN-ENZO and
DANIA-ANDREA.

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BIOLOGY OF THE MYCTOPHID FISH, *Diaphus theta* EIGENMANN AND EIGENMANN 1890, OFF THE OREGON COAST.

INTRODUCTION

Diaphus theta Eigenmann and Eigenmann 1890 is a representative of the most speciose genus of the family Myctophidae (Nafpaktitis, 1978). It is one of the most abundant mesopelagic fishes collected in the upper 200 m at night in oceanic waters off the Oregon Coast (Pearcy and Laurs, 1966; Pearcy, 1977; Pearcy et al., 1977).

Diaphus theta inhabits subartic and transitional waters of the North Pacific Ocean. It is found mainly north of 40° N in the eastern and western North Pacific, including waters of the Kurile-Kamchatka area, the Bering Sea and the Gulf of Alaska (Pearcy, Nemoto and Okiyama, 1979) and also extends as far south as 25° N off Central Baja California (Kawaguchi and Shimizu, 1978; Nafpaktitis, 1978).

Nafpaktitis (1978) includes *Diaphus theta* in a taxonomic complex that includes 14 other closely related species. He notes that *D. theta* is most similar to *D. hudsoni* from the South Pacific Ocean, hence these two species can be considered to be a biantitropical species pair.

Some aspects of the biology of *D. theta* off Oregon have been studied. *D. theta* has been described as a diel migrant, distributed between 300-600 m by day, with peak around 400 m, and in near surface waters (0-200 m) with peak at 50 m at night (Pearcy et al.,1977; Willis and Pearcy, 1980). Pearcy and Laurs (1966) found that nearly the same number of *D. theta* were captured per m^2 during the day and night periods, suggesting that it does not show visual avoidance of the trawls. Annual, seasonal (with higher summer catches) and inshore-offshore (with higher catches over the continental slope than the shelf) variations have been found in the abundances of *D. theta* off Oregon (Pearcy, 1964; Pearcy, 1977). *D. theta* has either small reduced, thick-walled swimbladders or thin-walled gas-filled swimbladders. They also have a high lipid content. Both these mechanisms may be used to attain neutral buoyancy (Butler and Pearcy, 1972; Neighbors and Nafpaktitis, 1982). *D. theta* feeds primarily on the euphausiid *Euphausia pacifica*, the copepods *Metridia lucens* and *Calanus* spp. and the amphipod *Parathemisto pacifica* (Tyler and Pearcy, 1975).

The purpose of this study is to investigate the growth and larval distribution of *D. theta* off Oregon and to relate inshore-offshore, annual and seasonal variations in distribution and abundance with oceanographical processes.

METHODS

Fish used in this study were collected with a 1.8-m Isaacs-Kidd Midwater Trawl (IKMT) (Isaacs and Kidd, 1953; Aron, 1962) equipped with a 5 mm mesh liner and a 0.5 m diameter, 0.57 mm mesh codend. Collections were made monthly from the R/V ACONA and the R/V YAQUINA between March 1961 and July 1967. the stations sampled were located along three parallels of latitude extending westward from the Columbia River mouth (Astoria), 46°14' N (81 samples from July 1961 to July 1965), from Newport, 44°40' N (94 samples from August 1961 to July 1967) and from Coos Bay, 43°22' N (69 samples from August 1961 to July 1965) (Fig.1). Stations at 28 km, 46 km, 84 km and 120 km from shore were routinely sampled. Stations ranging from 157 to 300 km from shore were sampled less frequently. All samples used in this study were from oblique tows collected at night from the surface to 200 m, except for collections at the 28 and 46 km stations off Newport where the average depth of water was 40 and 130 m respectively. In addition, 122 samples collected from March 1961 to April 1965 at NH-50 (93 km) off Newport, a station located over the outer edge of the continental slope, were also used in this study. Some of these

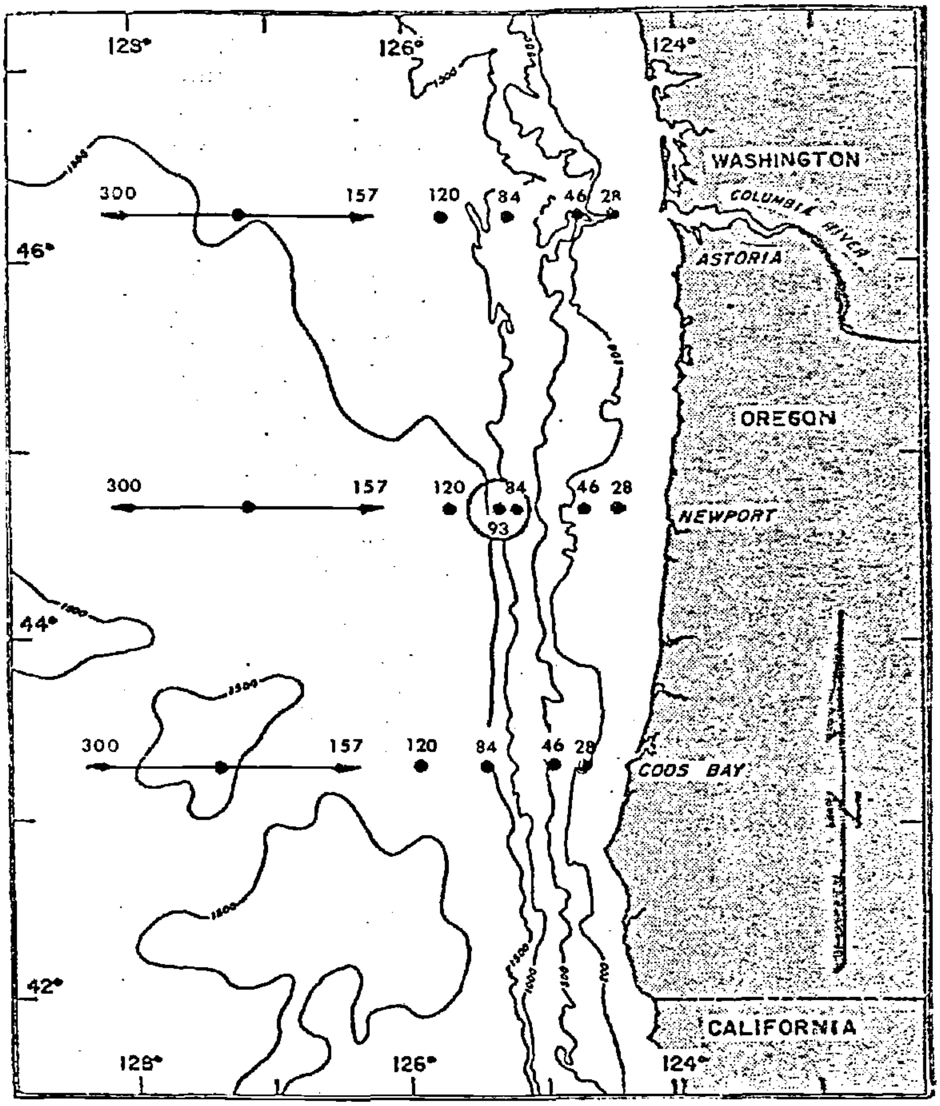

Fig.1. Locations of midwater trawl stations off Oregon. Numbers designate the distance in kilometers from the coast. Usually several stations were sampled between 157 and 300 km on each cruise. Depths are in fathoms. From Pearcy (1964).

samples were collected from a depth of 0 - 150 m using an IKMT with an opening-closing codend (Pearcy and Laurs,1966). For more details about the sampling see Pearcy (1964). Fish were preserved at sea in 10 % formalin in sea water and later transferred to 50 % isopropyl alcohol.

The sampling stations were divided into two groups: inshore stations located from 28 to 46 km from shore, and offshore stations located from 83 to 300 km from shore. The abundances of _D. theta_ were standardized to number per m^2. Average numbers per m^2 were calculated as total number of fish ÷ total volume of water filtered (in $10^3 m^3$) and converted to number per m^2 multiplying by (Depth/1,000).

All _D. theta_ were measured (standard length, SL) to the nearest mm, grouped into 5 mm length categories, and the numbers of fish in each category were added together from tows during a given month for a station or for inshore or offshore station groups. Some fish were frozen at sea, and defrosted and weighted in the laboratory to provide estimates on wet weight : length relationships.

The sagittal otoliths were dissected from 150 frozen fish, 17 to 70 mm SL, caught during September 1981. Otoliths were dried, immersed in xylene, and examined under a dissecting microscope at 50 magnifications using both transmitted and reflected light. The diameters of opaque and transparent rings were measured from the focus of the otolith with an ocular micrometer along the longest dimension of the otolith. Widths of the otoliths were also measured normal to the long axis of the otolith.

A total of 15 whole otoliths were ground, coated with a 60:40 Au:Pt alloy and examined with a scanning electron microscope (SEM).

RESULTS

GROWTH

Otolith morphology.

The otoliths of *Diaphus theta* were slightly concave on the median side and slightly convex in the lateral side. Although otoliths of small fish were more circular than those of the larger fish (Fig. 2), the relationship between the length and width of otoliths from all sizes of fish is linear:

$$\text{WIDTH} = .0608 + .758 \text{ LENGTH}$$

($r^2 = 0.986$, $n = 149$, Fig. 3). This indicates isometric growth of these two axes of the otolith for all lengths examined.

Otoliths of large *D. theta* have spines or protrusions projecting from the edge of the otolith. Some spines have a pointed apex while others are more rounded (Fig.2). These spines were only found on the otoliths from fish larger than 22 mm SL. A linear relationship occurred between the length of the otolith and the number of spines:

$$\text{NUMBER OF SPINES} = 3.340 \text{ OTOLITH LENGTH} - 2.571$$

($r^2 = 0.880$, $n = 135$).

Similarly,

$$\text{NUMBER OF SPINES} = 0.152 \text{ SL} - 2.388$$

($r^2 = 0.736$, $n = 136$, Fig.4). Considering only data for

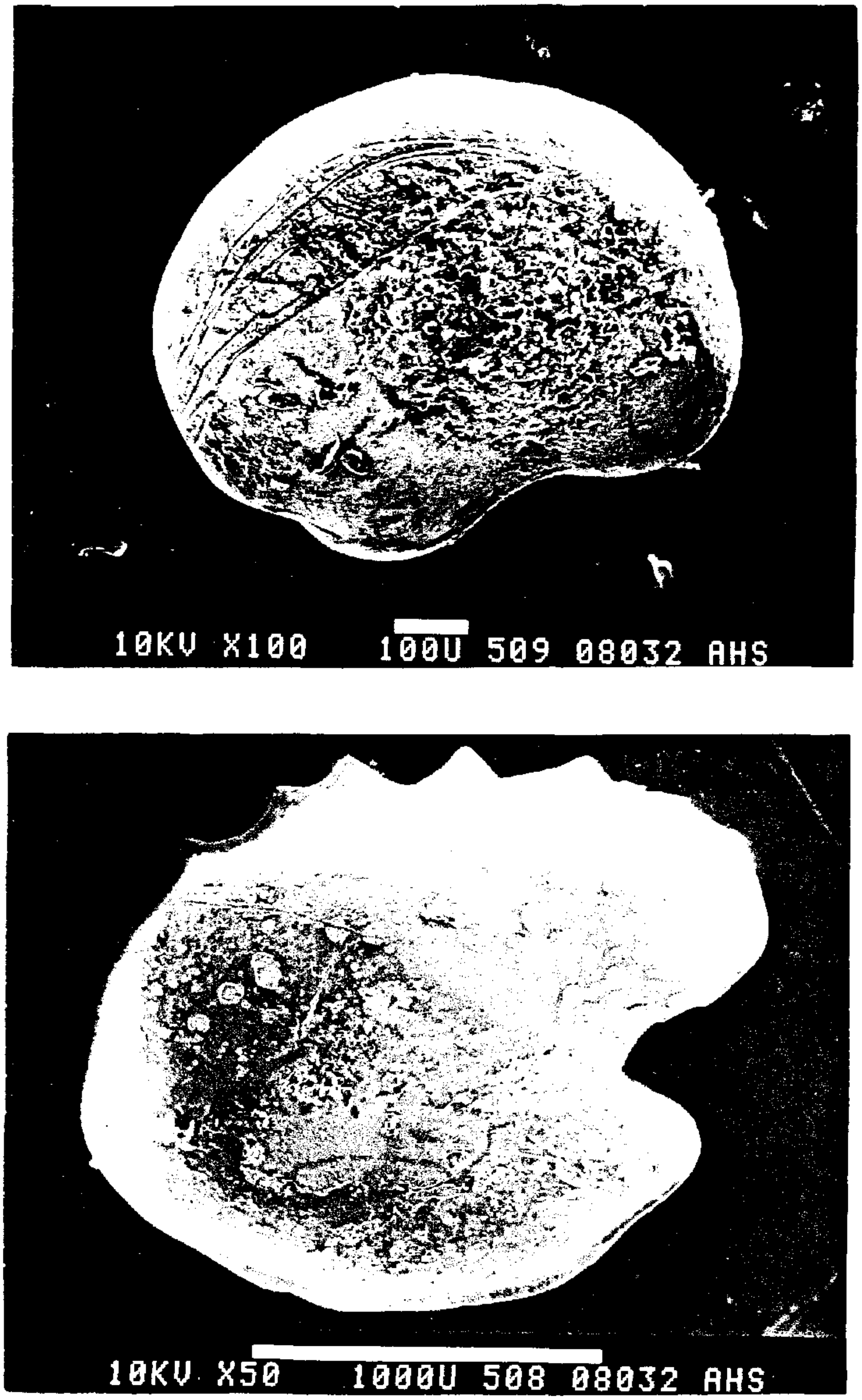

Fig. 2. Scanning electron micrographs of otoliths of *Diaphus theta*.
a. 18 mm standard length fish, 100x.
b. 47 mm standard length fish. 50x.

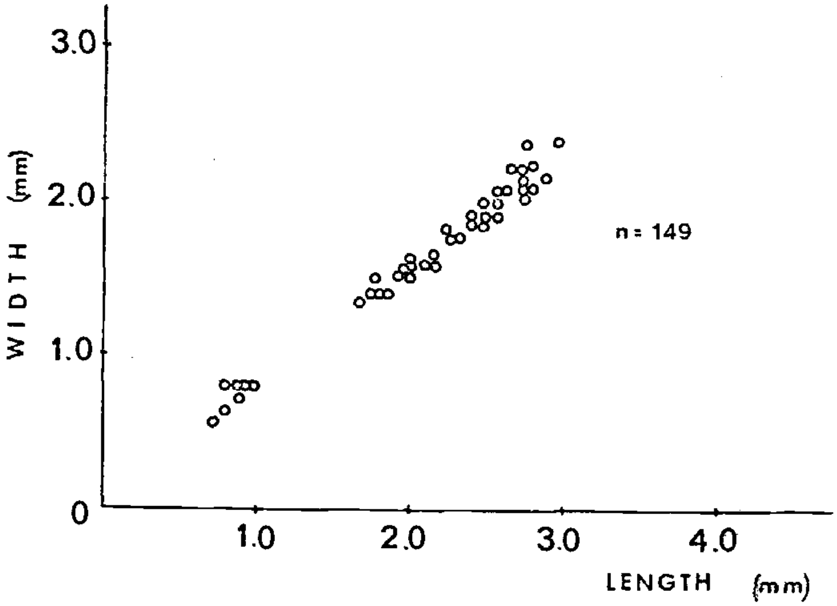

Fig. 3 . Length of the otolith vs. width of the otolith of *Diaphus theta*.

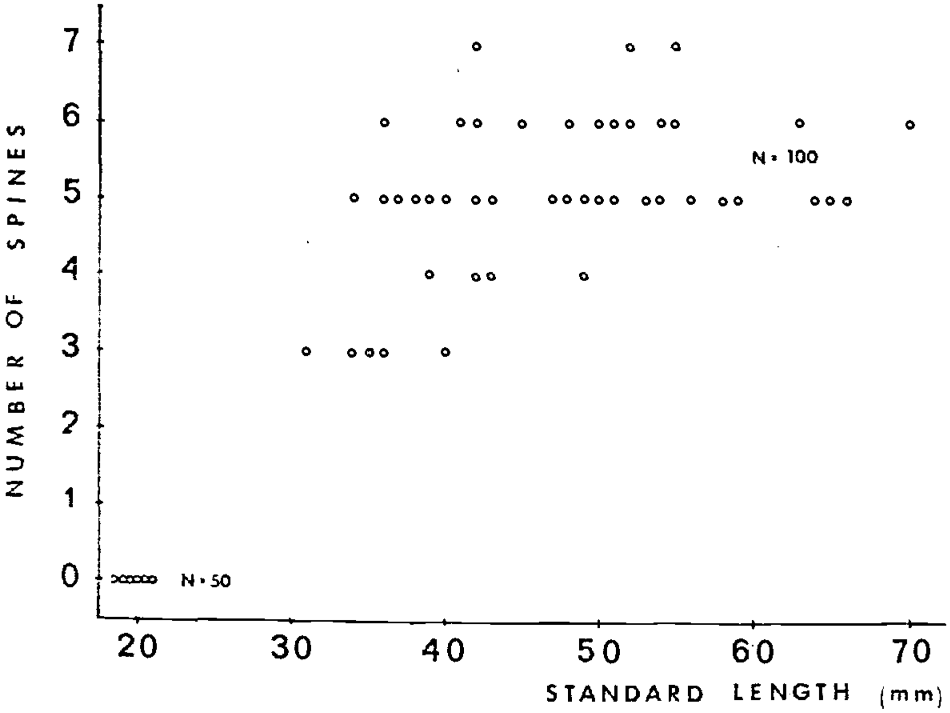

Fig. 4 . Standard length of the fish vs. number of spines present in the otolith.

fish with spiny otoliths (31 to 70 mm SL), the r^2 for these two regressions decreased to 0.17 and 0.14, respectively. Thus the high r^2's are produced by the presence of small fish that have no spines on the otoliths. Therefore the number of spines on otoliths of *D. theta* (found, for example, in stomachs of predators like albacore, bluefin tuna and bonito (Pinkas, Oliphant and Iverson, 1971) and *Sebastes flavidus* (Pereyra, Pearcy and Carvey, 1969) is a poor predictor of the size of fish.

Otolith analysis.

No detectable difference in size was found between the left and right otolith from a specimen, therefore the right otolith was used for diameter measurements of the growth rings and age determination. The relationship between the maximum diameter (length) of the otolith and the standard length of the fish was estimated (Fig. 5) so that length could be back-calculated from otolith diameters. Although an r^2 of 0.98 was obtained, the two length groups of fish included in the regression, 17 to 22 mm and 31 to 70 mm, do not fall along a common straight line. The classification model (Neter and Wasserman, 1974) indicated that the two regression lines for the two groups are significantly different ($P < 0.01$, $F = 80.47$), so regressions were calculated for the two groups separately: for the 31-70 mm group,

$$\text{STANDARD LENGTH} = 27.845\ \text{L.OTOLITH} - 15.4$$

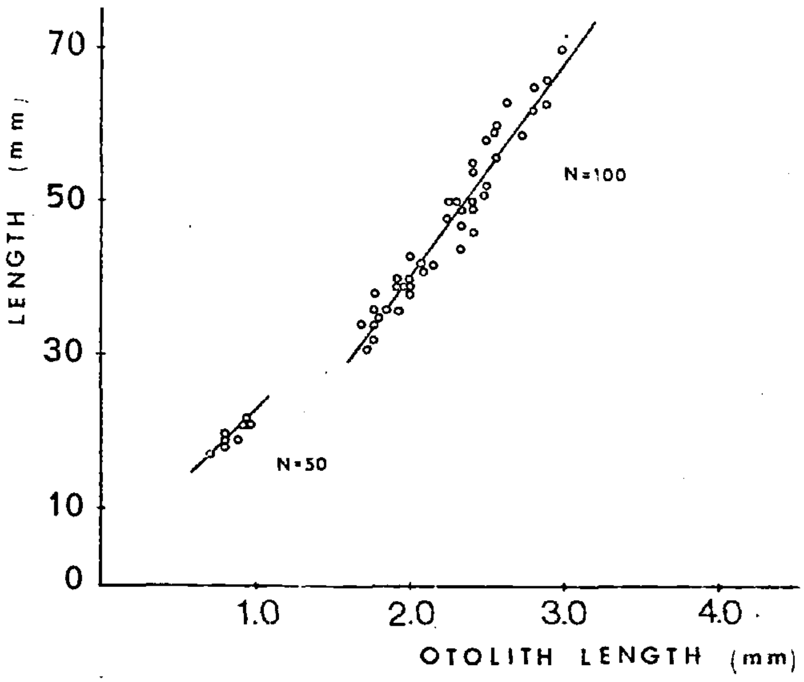

Fig. 5. Length of the otolith vs. Standard Length of the fish. Size group 17 - 22 mm (n=50) Size group 31 - 70 mm (n=100).

(r^2 = 0.939, n = 100); and for the 17 to 22 mm size group,

STANDARD LENGTH = 3.019 + 19.52 L.OTOLITH

(r^2 = 0.815, n = 49).

Alternating hyaline or transparent and opaque rings have been described in the otoliths of the myctophids Diaphus suborbitalis by Go, Kawaguchi and Kusaka (1977a), Notoscopelus elongatus kroeyeri and Benthosema glaciale by Gjosæter (1981 a,b) and Stenobrachius leucopsarus by Smoker and Pearcy (1970) and Adams (1979), and for other mesopelagic fishes such as Tactostoma macropus by Fisher (1980) and Leuroglossus schmidti by Adams (op.cit.). Go, Kawaguchi and Kusaka found that one transparent ring and one opaque ring were formed each year in the otoliths of D. suborbitalis from Suruga Bay, Japan: the transparent ring was formed during late summer through winter, and the opaque ring was formed during spring and early summer. Unfortunately, the otoliths used in this study were all from a single sample taken in September. All of the otoliths analyzed had transparent outer margins. This agrees with the findings of Go, Kawaguchi and Kusaka for D. suborbitalis during the same month. Based on this information I assumed that D. theta and D. suborbitalis have the same pattern of otolith growth with one hyaline and one opaque ring deposited each year.

The hyaline and opaque rings from which the diameters were measured are illustrated in Fig.(6) and data is summarized in Table (1). Mean otolith diameters increase

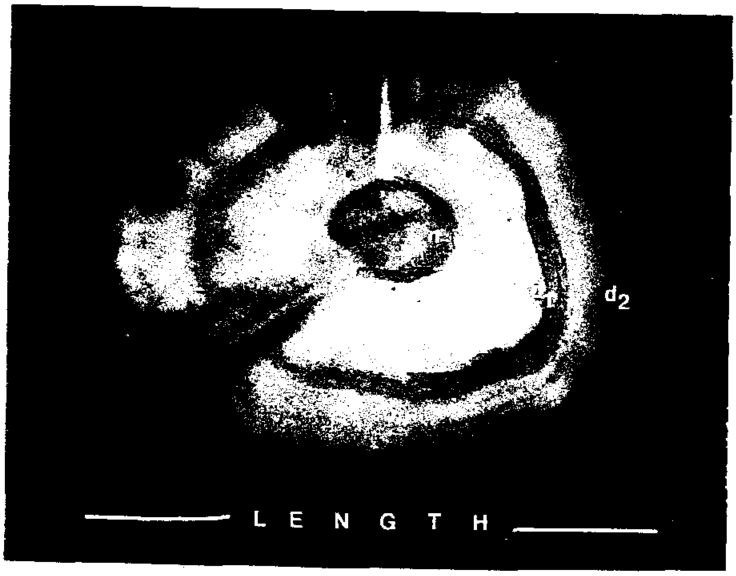

Fig. 6. Otolith of *D. theta* treated with xylene showing the hyaline and opaque rings.

Table 1. Range, Mean, Mode and Variance for ring diameter measurements of the otolith of *D. theta*.

Distance (mm)	Range (mm)	Mean (mm)	Mode (mm)	Variance (mm)	N
Nucleus	.380-.494	.431	.437	.0006	150
d_1	1.180-1.463	1.318	1.368	.0024	100
d_2	1.634-1.767	1.716	1.748	.0012	59
d_3	1.881-2.280	2.142	2.090	.0139	24

with each successive hyaline and opaque ring. Based on these results, a relationship between age and SL was established to separate the fish in age groups (Table 2). According to the assumptions of two rings per year, the d_1, d_2 and d_3 margins were associated with ages 1, 2, and 3 years, respectively. The fish with only one ring beyond the nucleus were considered the 0+ group, fish less than one year old. The mean standard length of these groups and their standard deviation are plotted vs. estimated age in Fig.(7).

Using the relationship between the otolith diameter and standard length, mean fish lengths at ages 1, 2, 3 were back-calculated. The estimated lengths are included in Table 2 and Fig. (7).

Otoliths from 6 D. theta were analyzed with the SEM to detect possible daily growth lines, already described as a common feature for several species of fishes from temperate waters (Pannella, 1974), including the myctophid S. leucopsarus (Methot, 1981). Otoliths of juvenile fish (17 to 22 mm SL) had 59 to 70 clearly defined rings (Fig.8) that were counted with a compound microscope. Ages of 59 to 70 days agree fairly well with the presumed ages of two months for 22.1 mm SL specimens of D. suborbitalis from Suruga Bay (Go, Kawaguchi and Kusaka, 1977b), suggesting that one ring is probably deposited each day.

Table 2. Age - standard length relationship of *Diaphus theta* based on direct otolith readings and back-calculation.

		Mean Standard Length (mm)				N/
Age in years	Range	Direct	SD	Back-calculated	SD	Age group
<1	17 - 22*	19.7	1.5	-----	---	50
1	31 - 42	37.7	3.0	21.3	1.37	41
2	40 - 55	50.3	3.7	32.2	0.81	35
3	53 - 70	63.3	1.2	42.2	3.34	24

* The sample analyzed did not include fish in the 23-30 mm size range.

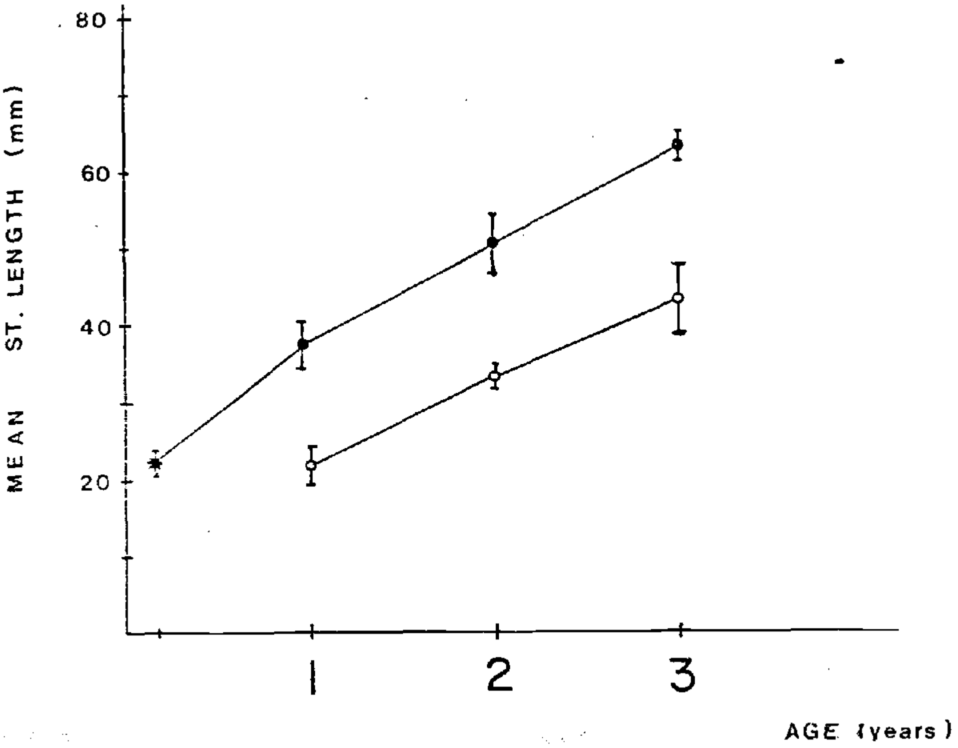

Fig. 7. Mean standard length vs. estimated age from direct otolith readings (•) and back-calculation (o). ✱ Estimate from daily growth increments.

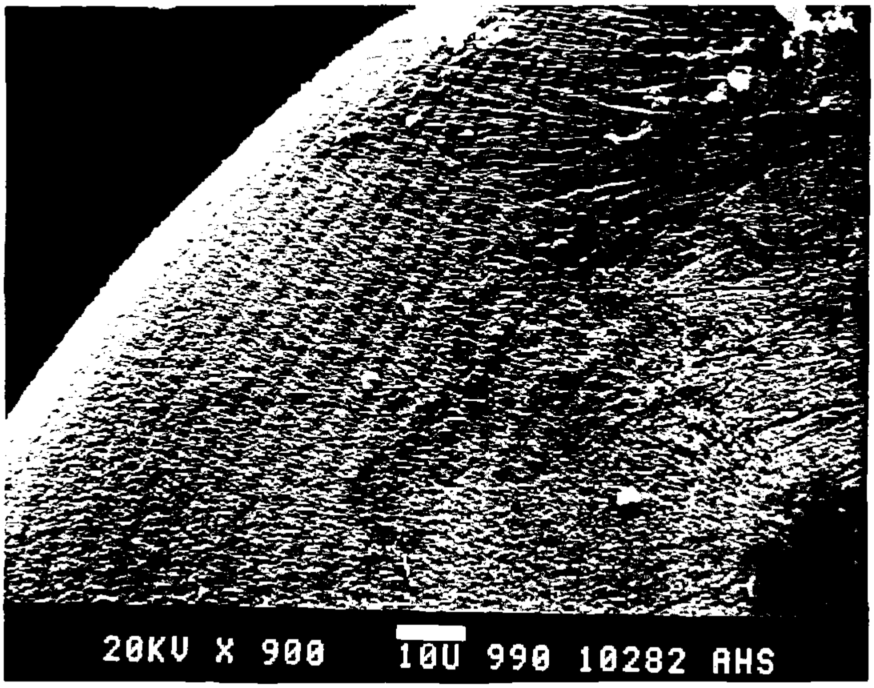

Fig. 8. Growth increments in *Diaphus theta* otolith. 21 mm fish SEM micrograph 900x.

Length frequency analysis.

The size frequency distributions of *Diaphus theta* collected at the offshore stations, where the largest catches and the most consistent seasonal sampling occurred, were generally comprised of two or three recognizable modes that could be followed through time (Fig. 9). These modes are assumed to represent year classes and the increasing length in them with time is assumed to be a measure of the average growth of the fish that survived.

The smallest *D. theta* (10 - 15 mm) usually occurred in collections during the summer and fall months. These small fish generally comprised a small percent of the total catch, except during the summer of 1965. Several series of collections illustrate a clear increase in average length of successive modes, e.g., the modal progression between September-October 1962 and August 1963 (Fig. 9).

To illustrate growth trends the median fish lengths of modal progressions are connected in Fig. (10). These median lengths were used to calculate a linear regression between length and time:

ST. LENGTH = 18.52 + 1.54 TIME (months)

(r^2 = 0.932 and n =107).

Since the recruitment of juvenile *D. theta* off Oregon generally starts during late summer through fall, July was set as the time of birth for the above calculations.

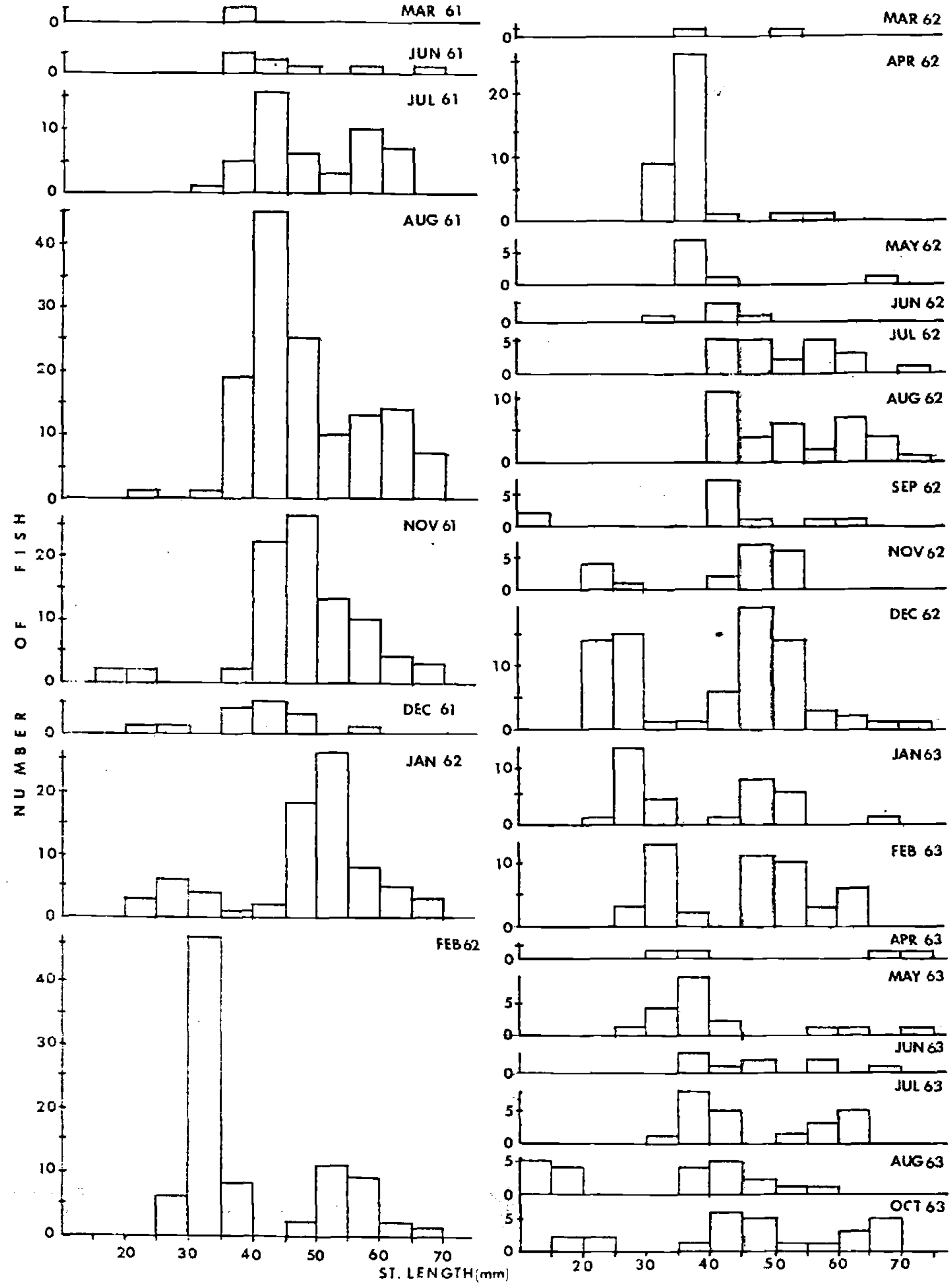

Fig. 9 . Length-frequency distributions of D.theta in the offshore stations. 1961 - 1967.

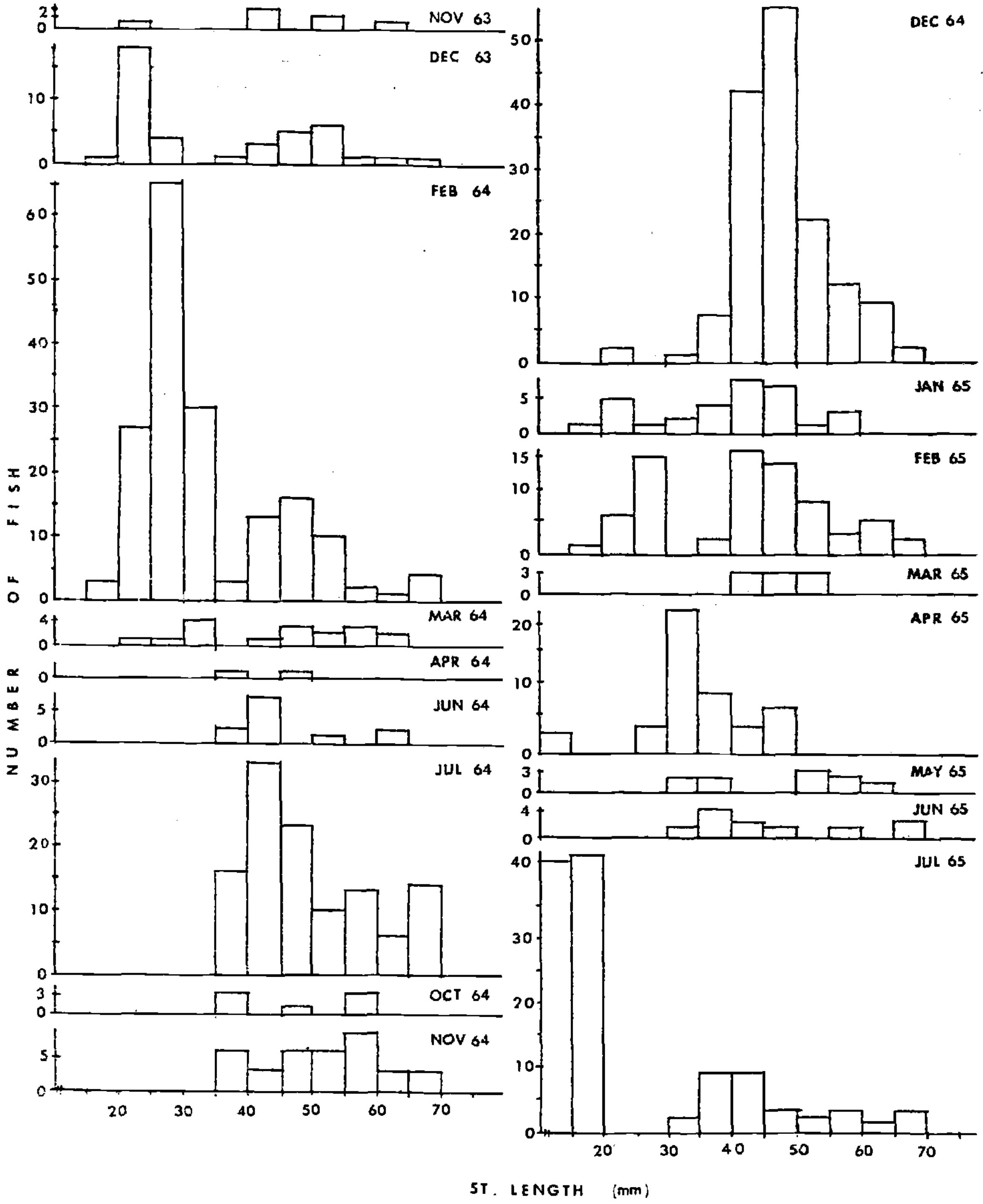
NOV 63
DEC 63
FEB 64
MAR 64
APR 64
JUN 64
JUL 64
OCT 64
NOV 64
DEC 64
JAN 65
FEB 65
MAR 65
APR 65
MAY 65
JUN 65
JUL 65
NUMBER OF FISH
0
5
10
20
30
40
50
60
20
30
40
50
60
70
ST. LENGTH (mm)

Fig. 9 . cont.

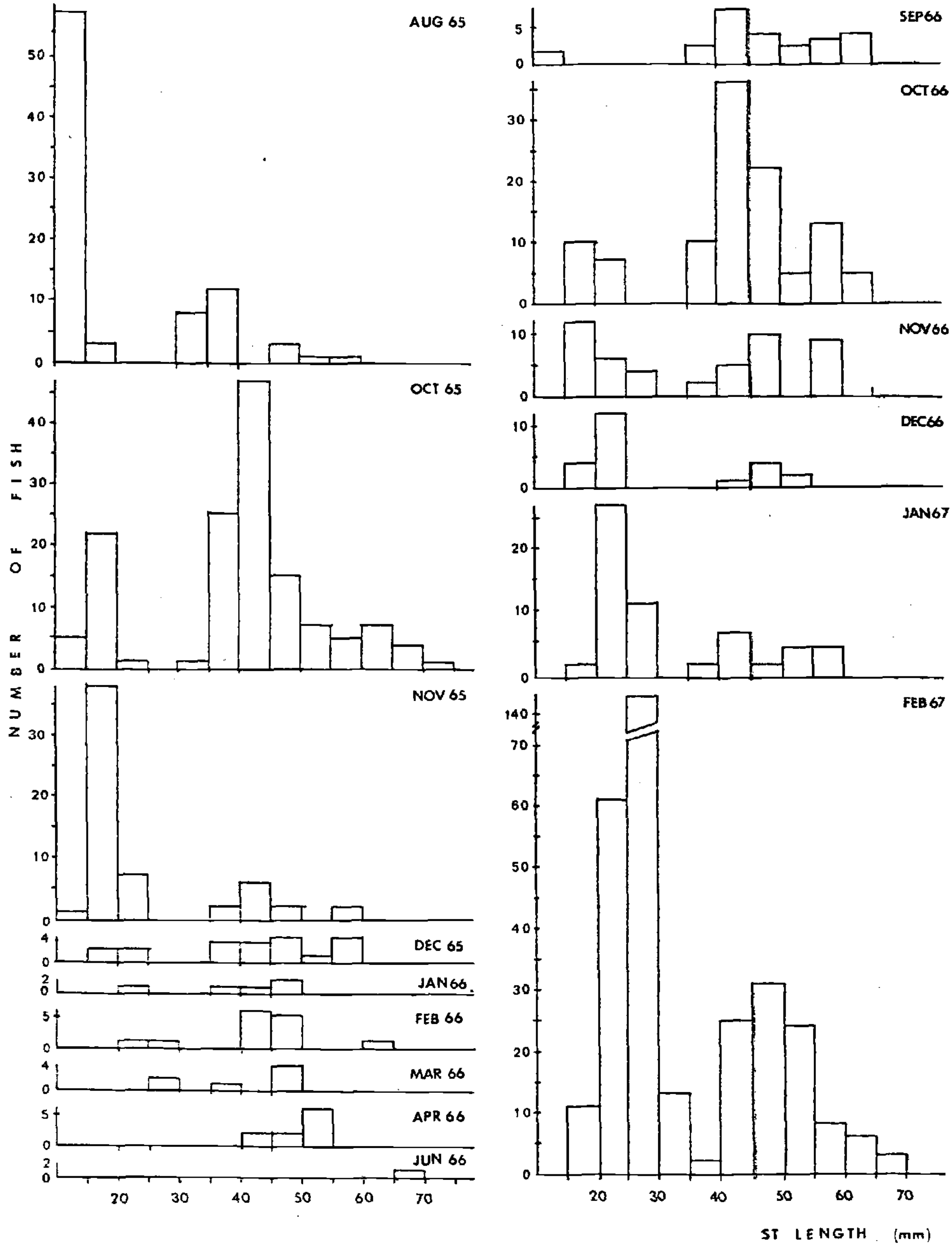
AUG 65
OCT 65
NOV 65
DEC 65
JAN 66
FEB 66
MAR 66
APR 66
JUN 66
SEP66
OCT66
NOV66
DEC66
JAN67
FEB67
NUMBER OF FISH
ST LENGTH (mm)
20
30
40
50
60
70
0
10
140

Fig. 9 . cont.

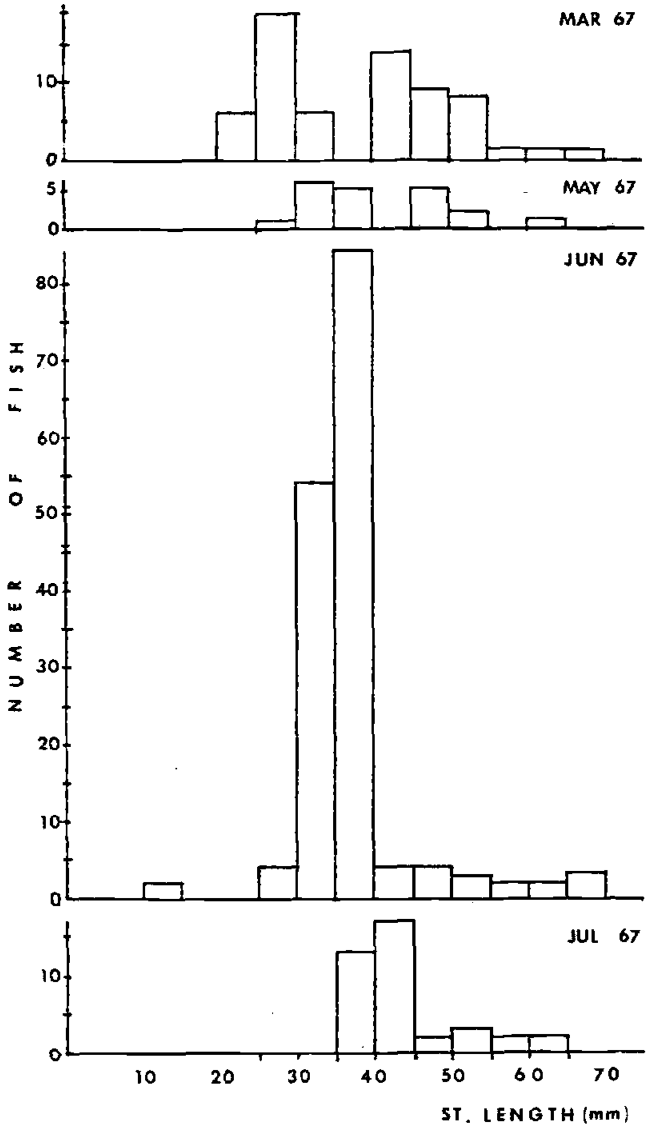
MAR 67
MAY 67
JUN 67
JUL 67
NUMBER OF FISH
0
5
10
20
30
40
50
60
70
80
ST. LENGTH (mm)

Fig. 9 . cont.

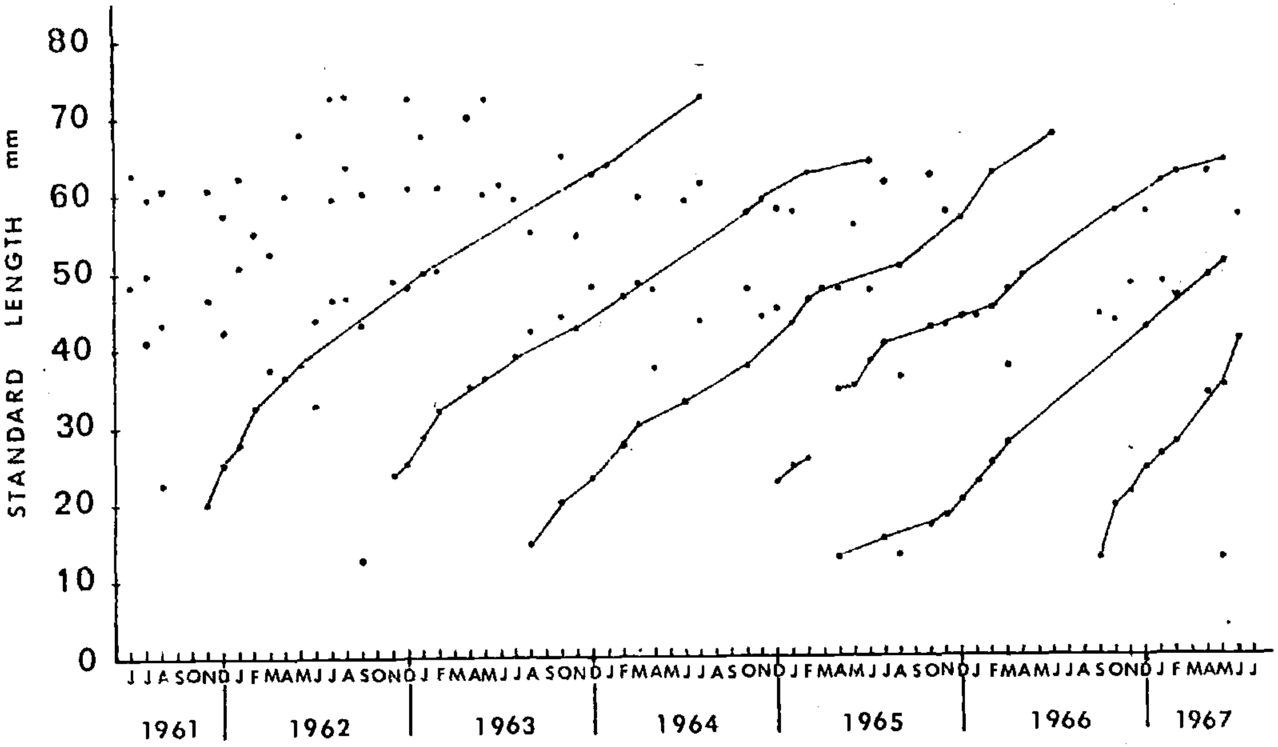

Fig. 10. Length frequency distribution medians of *D. theta* from offshore stations. 1961 - 1967 Midwater trawls.

Comparison of the three methods of aging.

Mean growth curves derived from the length frequency analysis, direct aging by otoliths and back-calculation from growth ring diameters are compared in Fig. (11). The growth curves derived from direct aging by otoliths and the length frequency analysis are similar. The growth curve derived from the back-calculation using the otolith diameters falls below the other two curves giving lower average SL estimates. Such difference is not unusual. It has also been observed in *D. suborbitalis* by Go, Kawaguchi and Kusaka (1977b), as well as in *Benthosema glaciale* and *Notoscopelus elongatus kroeyeri* by Gjosæter (1981a,b), *Tactostoma macropus* by Fisher (1980), *Ammodytes dubius* by Scott (1973) and *Ammodytes tobianus* by Reay (1972).

Several explanations have been postulated for this phenomenon. Go, Kawaguchi and Kusaka, and Gjosæter attributed it to Lee's phenomenon (Ricker, 1975), while Fisher attributed it to uncertainty in the time of hyaline ring deposition and progressive delay with age in the onset of the deposition, or resorption, of the otolith margin, a possibility also suggested by Scott. Reay thought that the opaque otolith material was initially deposited by "ingrowtH' into the hyaline material present at the edge of the otolith. Further studies and samples from other seasons are required to establish if any of these explanations explain the observed differences between direct and back-calculated growth curves of *D. theta*.

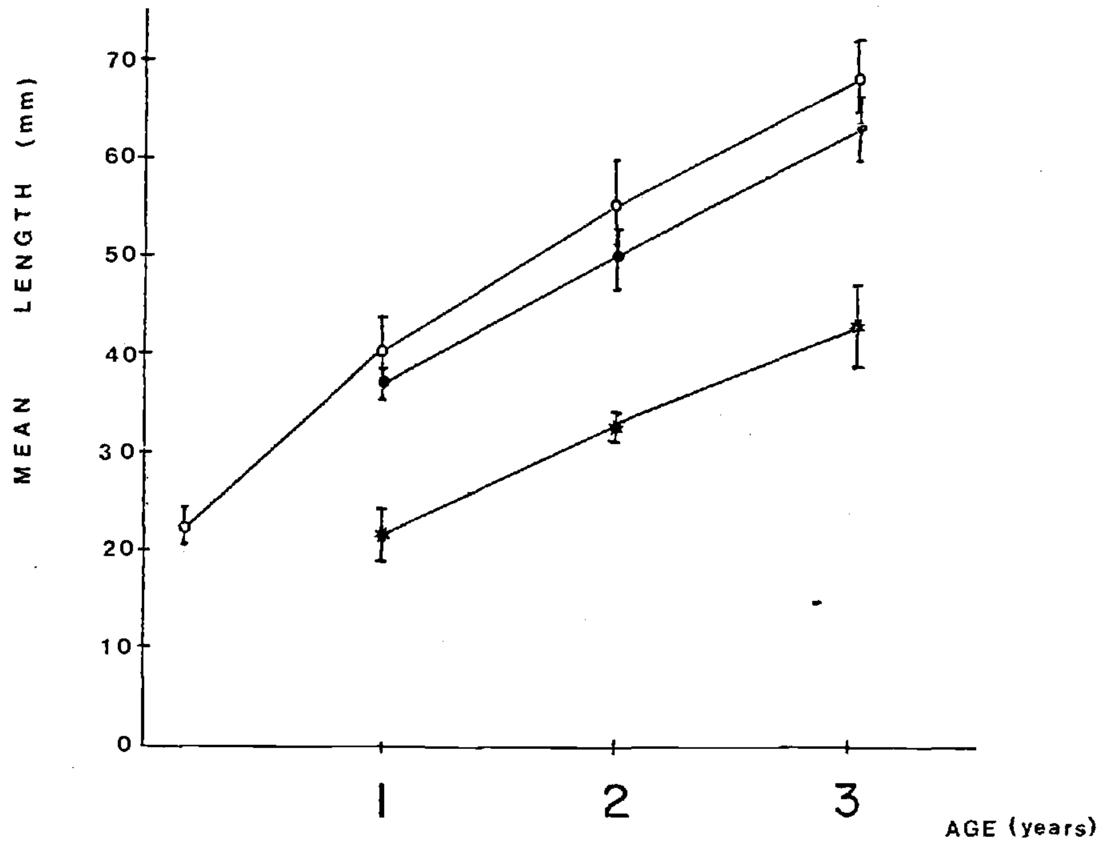

Fig. 11. Mean growth curves derived from length frequency analysis (o), otolith analysis (•) and back-calculation from growth ring diameters (*).
The vertical line represents one standard deviation.

Weight - Length relationship.

The relationship between standard length of the fish and its wet weight is exponential (Fig. 12), and is described by the equation:

$$\mathrm{LN(WEIGHT,\ g)} = -12.549 + 3.362\ \mathrm{LN\ (ST.LENGTH,\ mm)}$$

($r^2 = 0.989$ and $n = 123$) or,

$$\mathrm{WEIGHT} = .0000035 * \mathrm{ST.\ LENGTH}^{3.362}$$

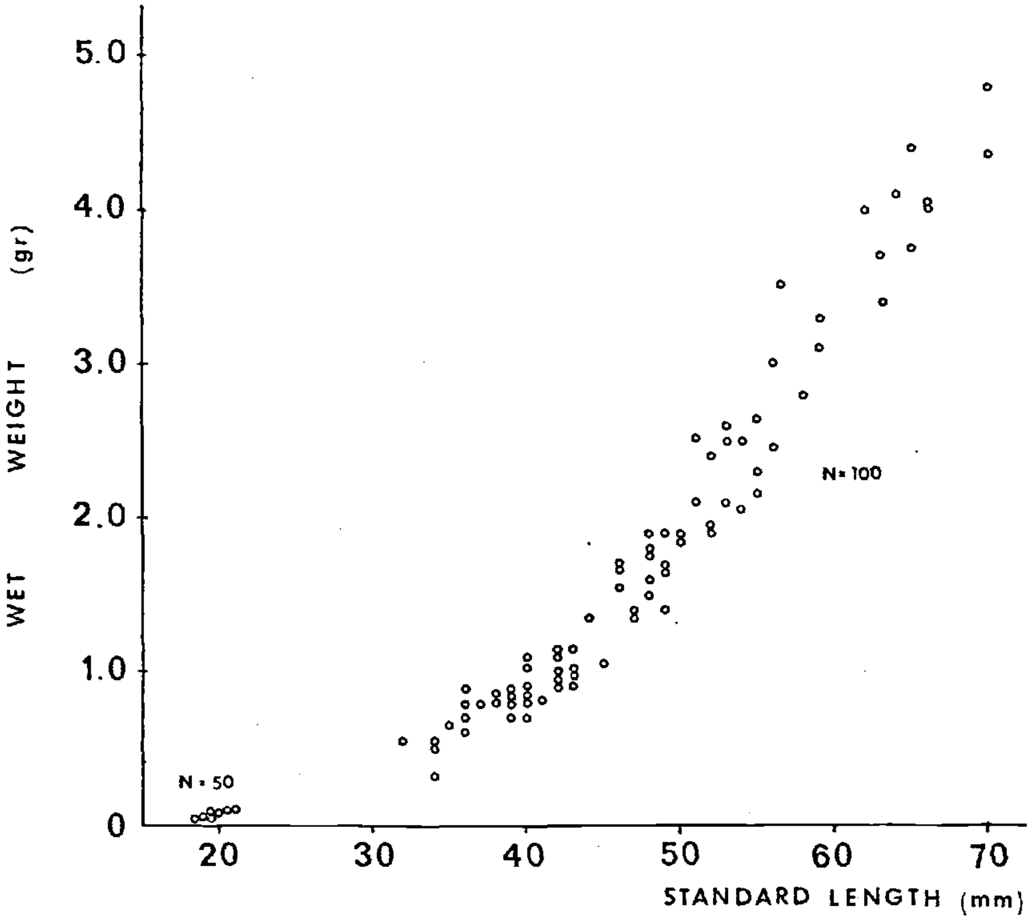

Fig. 12 . Standard length of the fish vs. Wet weight of *Diaphus theta.*

LARVAL DISTRIBUTION

Larvae of *D. theta* have seldom been reported in ichthyoplankton surveys off the Oregon Coast. Richardson, Laroche and Richardson (1980) did not include it in their larval assemblages, and Richardson and Pearcy (1976) only noted the occurrence of *D. theta* larvae in " southern stations ". Richardson (1973) reported 12 *D. theta* (8 - 13 mm) west of longitude 125°30' W off Oregon. Off the California coast all larval *D. theta* were captured between April and July on the CalCOFI cruises of 1956, a year when *D. theta* was abundant off California Moser, pers. comm.). The largest concentrations of *D. theta* larvae were found between 37° and 42° N off northern California (Fig. 13).

Two cruises during May 80 and August 80 conducted cooperatively by the National Marine Fisheries Service and USSR off the west coast of North America from 48°N to 40° N (Kendall and Clark, 1982 a,b), also provide information on the distribution of the larvae of *D. theta* caught in 60 cm bongo nets (.505 mm mesh) made with a maximum of wire out at each station during day and night sampling periods. Both cruises occupied stations between 5.6 and 370 km from shore. The latitudinal range of *D. theta* varied between the two

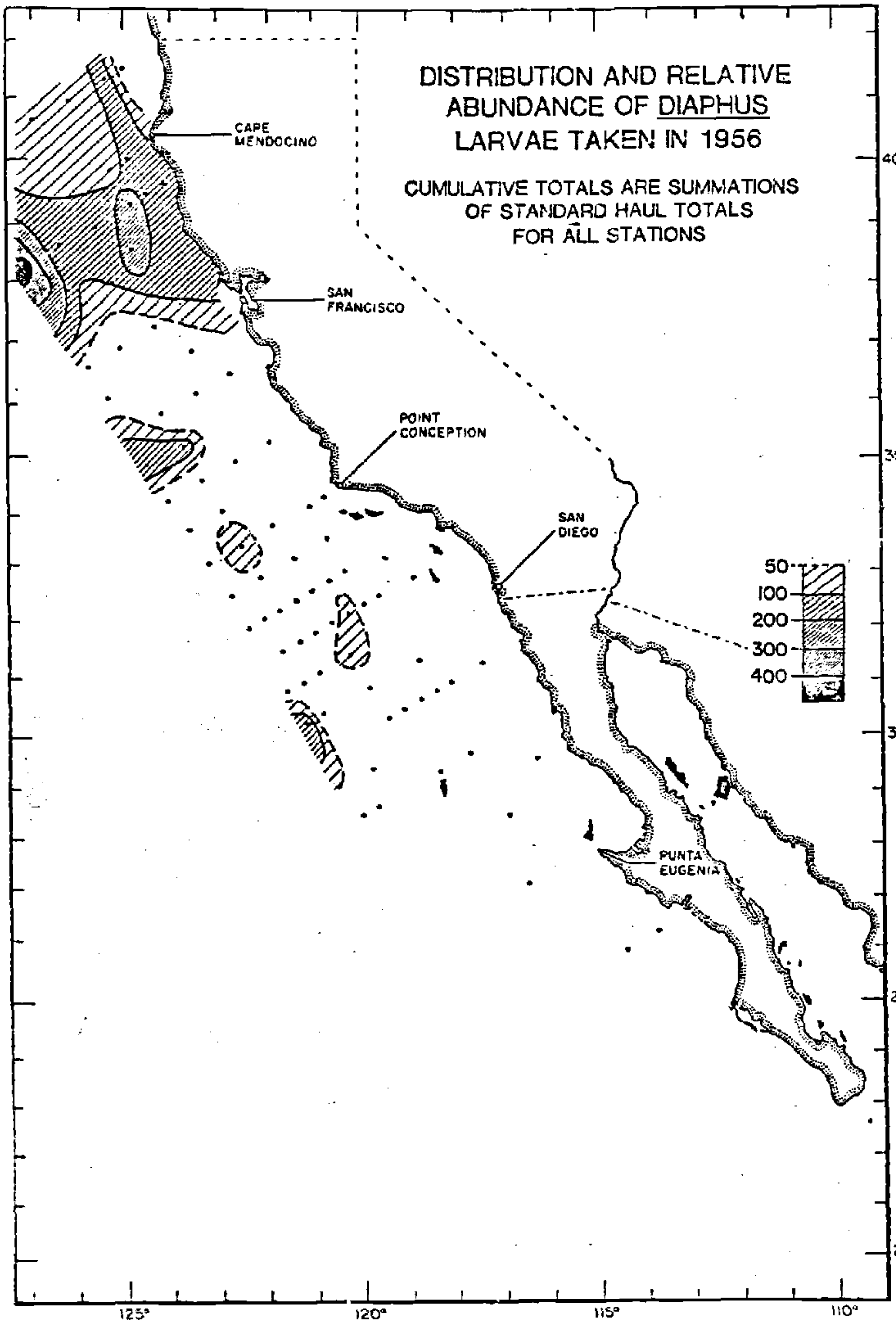

Fig. 13. Distribution and relative abundance of *Diaphus* larvae taken in 1956 off California. From Moser and Ahlstrom (in prep) used with permission.

cruises. IN May larvae were found between 40°N and 43°20'N, with highest catches per m^2 north of 42°N (Table 3). Waldron (1972) also found the largest abundances of *D. theta* larvae between 42° and 43°N during April and May 1967, reporting only 5% of the larvae north of that area but south of 46°N. In August, Kendall and Clark found larvae at all latitudes up to 46°N (Fig. 14) with largest catches of larvae per m^2 again between 42° and 44°N. Thus occurrence of *D. theta* larvae extended northward during the summer. Even though sampling was conducted as far north as 48°N (Kendall and Clark, 1982 a,b) and 51°N (Waldron, 1972), larvae of *D. theta* were not collected in any sample off the Washington and British Columbia coasts. This distribution of larvae suggests that *D. theta* may not spawn north of transitional waters in the California Current.

The mean length and size range of the larvae also differed between the two cruises (Fig. 15). Larvae were generally smaller and had a narrower size range in May than August (May: $\bar{X}$ = 3.44 mm, Range= 2.6 - 5.8 mm, SD= 0.63; August: $\bar{X}$ = 7.34 mm, Range= 3.1 - 16.5 mm, SD= 2.50).Larvae caught during the late summer included sizes that were similar to the smallest sizes caught in the IKMT samples (see length frequency analysis).

Inshore-offshore variations in the abundance of larvae, calculated from the average catches per 10 m^2 for each 1° of longitude (Table 3), show that in May *D. theta* larvae

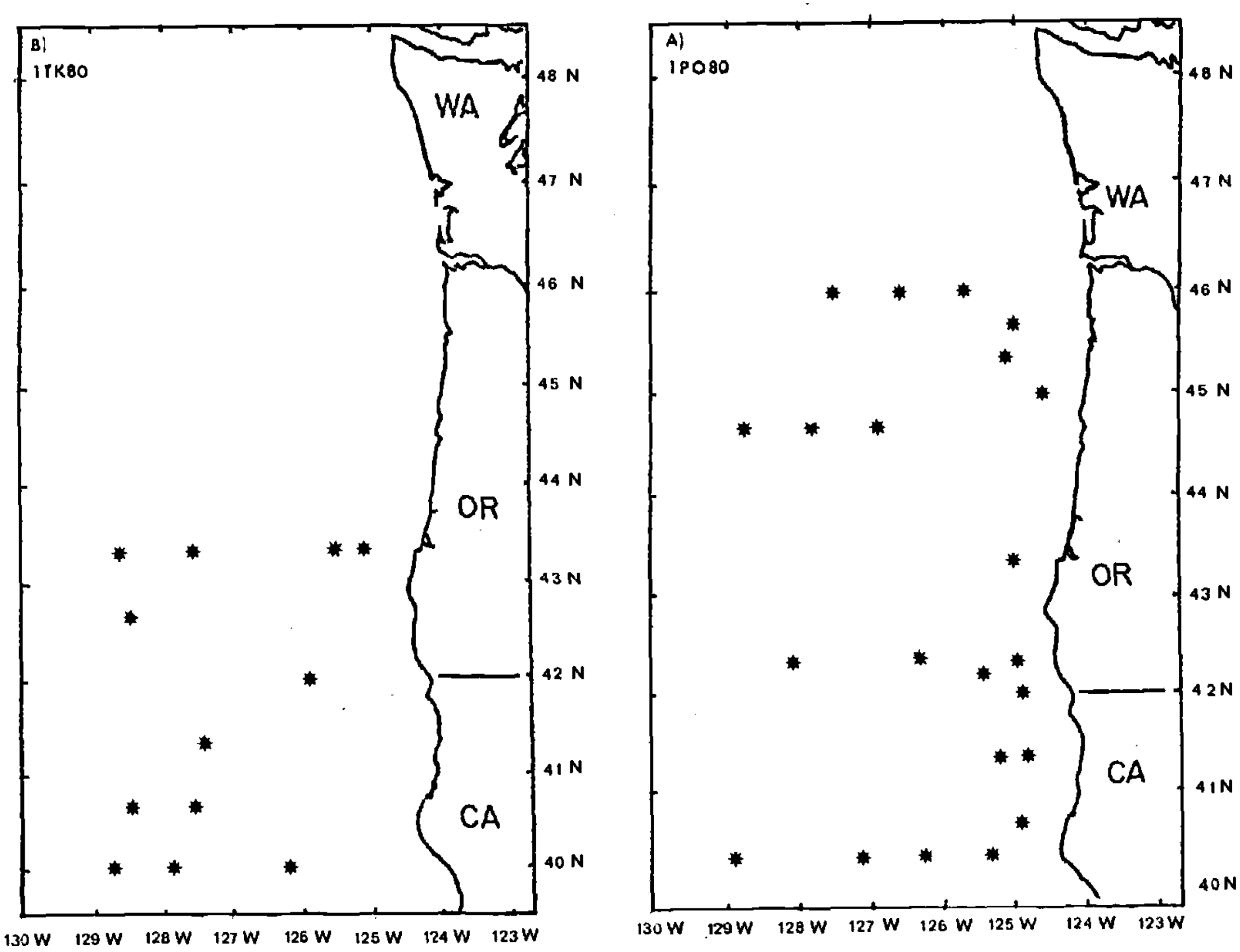

Fig. 14. Positive occurrence of *D. theta* larvae from the cruises 1TK80 (April-May) and 1PO80 (August) off northern California, Oregon and Washington.

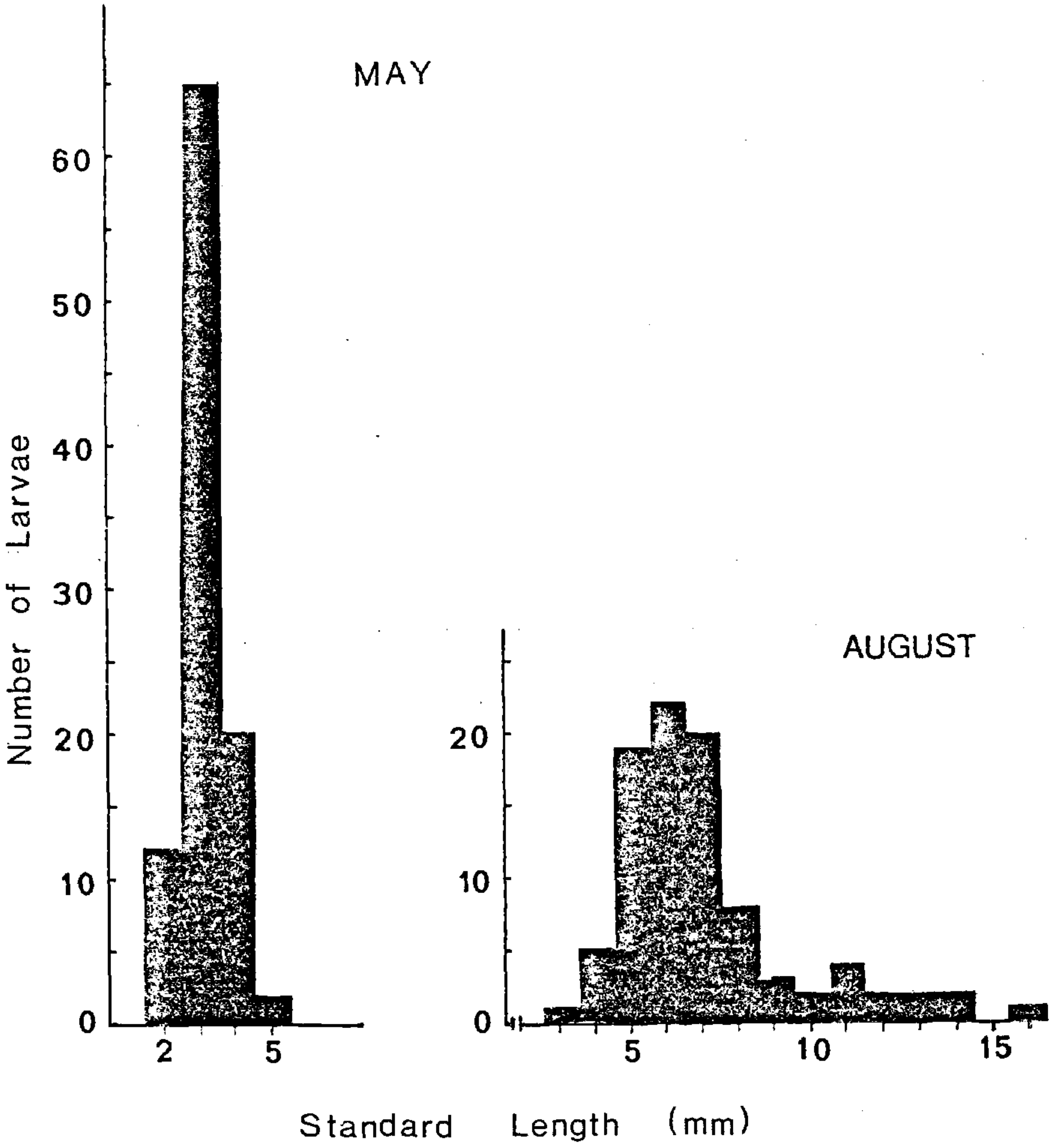

Fig. 15 . Length frequency distribution of D. theta larvae caught during the cruise 1TK80 (May) and 1PO80 (August).

Table 3. Distribution of *D. theta* larvae according to: a) latitudinal range and b) longitudinal range for cruise 1TK80 (MAY) and cruise 1PO80 (AUGUST), using the number of larvae and the average number of larvae per 10 m^2.

a.

	MAY	
Latitude range	N	Average #/ 10m^2
40° N - 42° N	11	14.5
42° N - 44° N	89	122.0
Total	100	

	AUGUST	
Latitude range	N	Average #/ 10m^2
40° N - 42° N	18	13.71
42° N - 44° N	51	54.83
44° N - 46° N	21	14.89
Total	90	

b.

Long. range	km offshore	N	$\bar{X}$ #/ 10m^2
124°W - 125°W	0 - 80	0	0.0
125°W - 126°W	80 - 165	18	48.67
126°W - 127°W	165 - 245	1	7.00
127°W - 128°W	245 - 320	7	13.75
128°W - 129°W	320 - 370	74	152.75
Total		100	

Long. range	km offshore	N	$\bar{X}$ #/ 10m^2
124°W - 125°W	0 - 80	14	14.29
125°W - 126°W	80 - 165	14	15.00
126°W - 127°W	165 - 245	39	59.25
127°W - 128°W	245 - 320	8	16.67
128°W - 129°W	320 - 370	15	32.33
Total		90	

were most abundant between 125° and 126° W and 128° and 129° W (80 to 165 km and 320 to 370 km offshore respectively). Highest catches were farthest offshore. No larvae were caught within 80 km from the shore, which agrees with the information by Richardson (1973). In August, abundance was more uniform, with highest catches between 126° and 127° W (165 to 245 km offshore). In this month larvae were caught east of 125° W, over the continental slope and shelf.

DISTRIBUTION AND ABUNDANCE

The average monthly IKMT catches per m^2 were calculated for the inshore and offshore stations of the three sampling areas (Coos Bay, Newport and Astoria) and are shown in Figs. 16 and 17. The significance of annual, seasonal and inshore-offshore variations were tested with One-Way ANOVA (Snedecor and Cochran, 1980) and Mann-Whitney U tests (Conover, 1971).

Annual variations.

Average annual abundances of *D. theta* were calculated for the inshore and offshore regions off Oregon for each year, 1961 - 1967 (Fig.18). Significant ($P < 0.01$) differences between the average inshore and offshore catches per m^2 were found only off Newport, where highest catches were made in the offshore region. Differences between inshore and offshore catches were not significant off Coos Bay and Astoria. In general, the interannual trends in abundance of *D. theta* are similar in the inshore and offshore regions.

The average annual catches per m^2 among the inshore regions were significantly ($P<0.01$) higher off Coos Bay than off Newport and Astoria. In the offshore region the annual average catches per m^2 off Newport and Coos Bay were significant ($P < 0.01$) higher than the catches per m^2 off Astoria. Differences were not significant between Newport

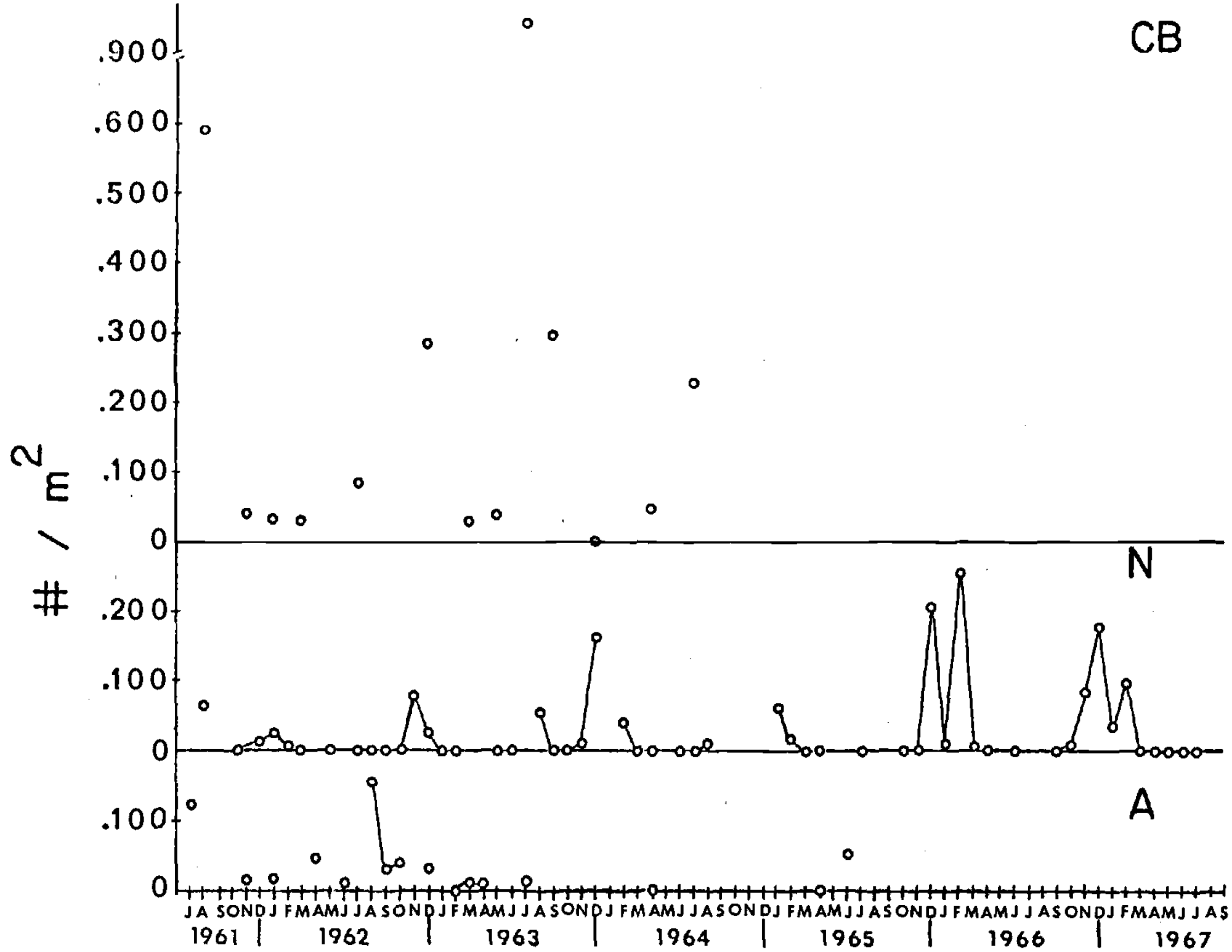

Fig. 16 . Average monthly catches per m^2 of D.theta off Oregon in the inshore region.
CB= Coos Bay, N= Newport, A= Astoria.

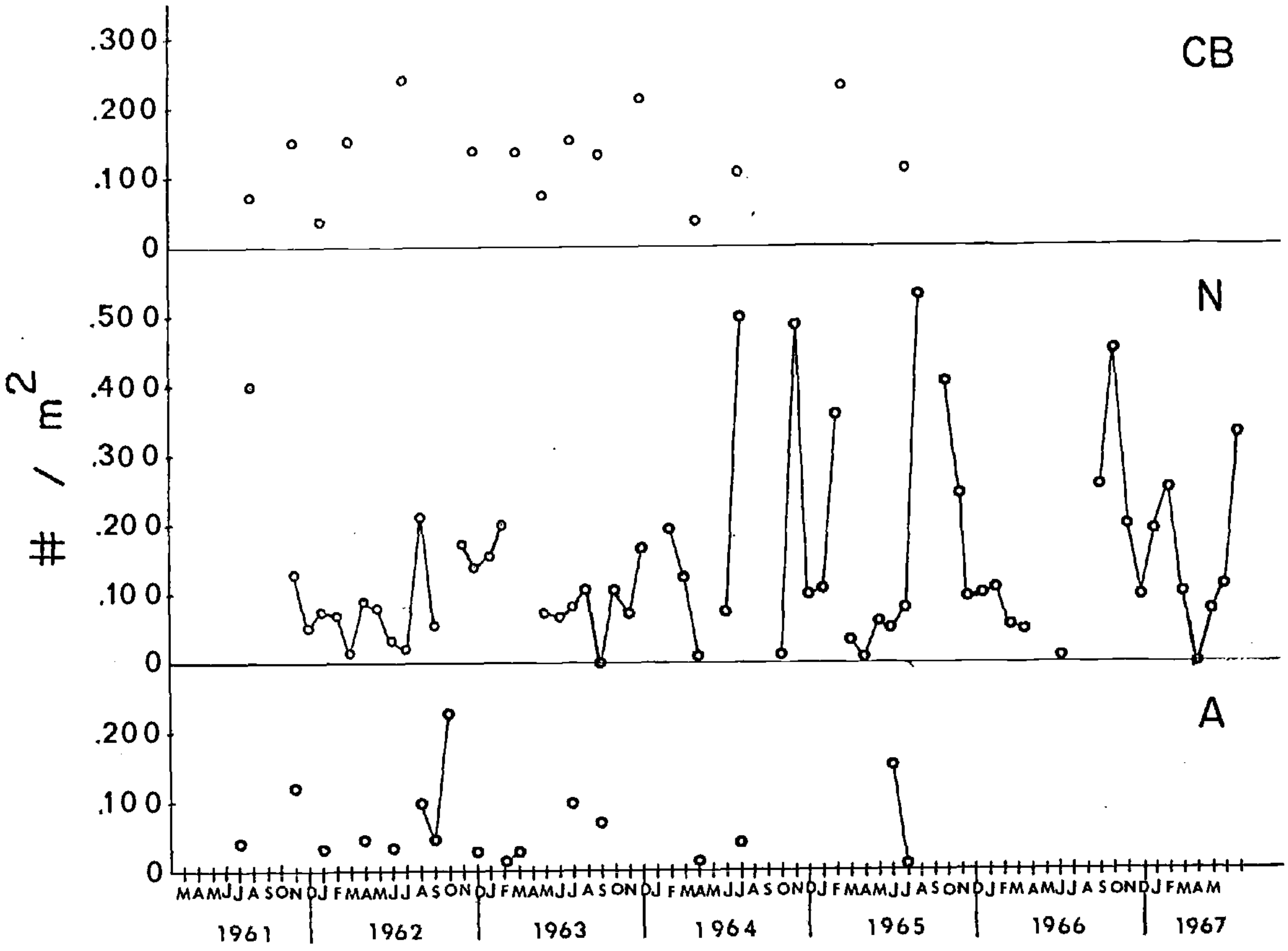

Fig. 17. Average monthly catches per m^2 of D.theta off Oregon in the offshore region. CB= Coos Bay, N= Newport, A= Astoria.

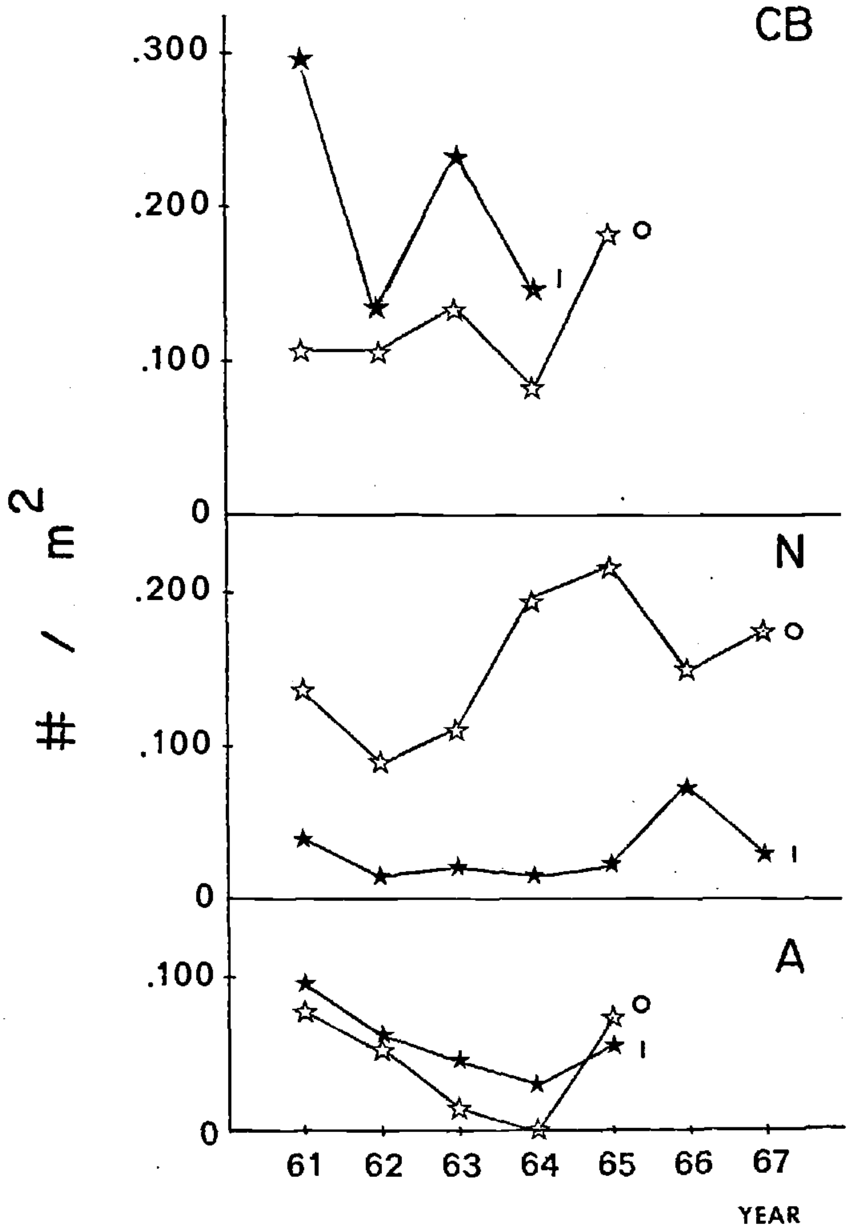

Fig. 18. Annual average abundance (# per m^2) of D.theta (1961 - 1967) in the inshore (I) and offshore (O) regions off Oregon. CB= Coos Bay, N= Newport A= Astoria.

and Coos Bay.

Seasonal variations.

Average abundances per m^2 of D. theta were calculated for each season in the inshore and offshore regions off Oregon for the period 1961 - 1967 (Fig. 19, where winter includes January, February and March; spring, April, May and June; summer, July, August and September; and fall, October, November and December). The average catches per m^2 were higher in the offshore than in the inshore region during the spring, fall and winter in all three sampling areas. In the inshore region they were highest during the summer off Coos Bay and Astoria. No D. theta was caught inshore during the spring off Newport. In the offshore region the highest seasonal peaks occurred during the fall off Astoria and Coos Bay and during the summer off Newport. Significant seasonal varaiations were found off Coos Bay in the inshore region and off Newport in the offshore region ($P < 0.01$).

Size composition of the catches.

The seasonal changes in the size composition of D. theta were analyzed for the three areas of sampling to determine the incidence of the different age groups of D. theta collected in the inshore and offshore regions. Two major trends were observed. Age group 0 fish formed a much larger percentage of the catches in the offshore than the inshore region off Newport (Table 4). Age group 0 also

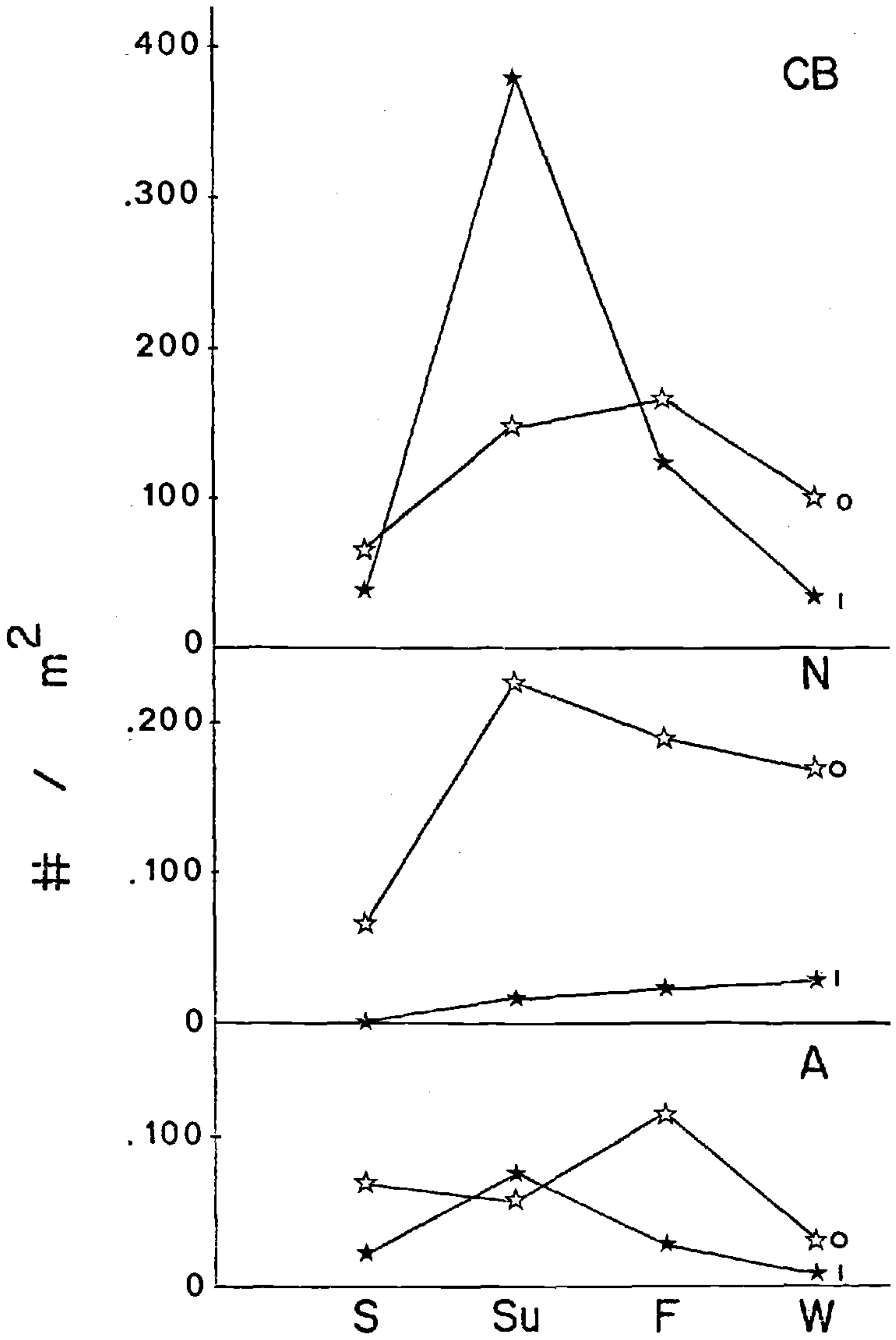

Fig. 19. Average seasonal catches per m^2 of D.theta in the inshore(I) and offshore (O) regions off Oregon. CB= Coos Bay, N= Newport A= Astoria.

Table 4. Percentage composition of age groups of *D. theta* in the inshore and offshore regions off Newport during the four seasons.

INSHORE	AGE GROUP					
SEASON	0+	I	II	III	>III	Total
WINTER	2.00	35.00	59.00	4.00	0.00	100
SPRING	0.00	0.00	0.00	0.00	0.00	0
SUMMER	0.00	28.57	34.29	34.29	2.85	100
FALL	8.77	48.25	40.35	2.63	0.00	100

OFFSHORE	AGE GROUP					
SEASON	0+	I	II	III	>III	Total
WINTER	47.83	20.19	23.17	8.81	0.00	100
SPRING	1.69	80.59	10.55	6.33	0.84	100
SUMMER	40.86	30.54	12.90	14.84	0.86	100
FALL	22.54	32.37	30.11	14.49	0.48	100

form only a small percent of the catch in both the inshore and offshore regions off Astoria and Coos Bay (Tables 5 and 6) where the age groups I - III were most common.

These size compositions indicate that age 0 *D. theta* were a major component of the offshore peaks that occurred in the summer and winter off Newport (Fig. 17 and 19) while larger fish were the principal component of the high inshore catches in the summer off Coos Bay and the winter off Newport (Fig. 16 and 19).

Table 5. Percentage composition of age groups of *D. theta* in the inshore and offshore regions off Coos Bay during the four seasons.

INSHORE	AGE GROUP					
SEASON	0+	I	II	III	>III	Total
WINTER	4.35	39.13	34.78	8.69	13.04	100
SPRING	0.00	60.00	40.00	0.00	0.00	100
SUMMER	0.90	44.50	26.00	26.90	1.70	100
FALL	18.40	14.30	57.10	10.20	0.00	100
OFFSHORE	AGE GROUP					
SEASON	0+	I	II	III	>III	Total
WINTER	21.40	41.67	11.90	25.00	0.00	100
SPRING	0.00	83.33	8.33	8.33	0.00	100
SUMMER	1.71	36.70	24.78	34.19	2.60	100
FALL	27.00	22.00	47.00	4.00	0.00	100

Table 6. Percentage composition of age groups of *D. theta* in the inshore and offshore regions off Astoria during the four seasons.

INSHORE	AGE GROUP					
SEASON	0+	I	II	III	>III	Total
WINTER	0.00	0.00	0.00	100.00	0.00	100
SPRING	0.00	46.15	46.15	7.70	0.00	100
SUMMER	0.00	40.00	27.62	31.43	0.95	100
FALL	0.00	15.38	84.62	0.00	0.00	100

OFFSHORE	AGE GROUP					
SEASON	0+	I	II	III	>III	Total
WINTER	0.00	15.38	23.08	53.85	7.69	100
SPRING	0.00	78.57	14.29	7.14	0.00	100
SUMMER	0.00	38.89	16.66	37.04	7.41	100
FALL	2.32	27.91	46.51	23.26	0.00	100

DISCUSSION

Seasonal and inshore-offshore trends in the abundances and size composition of D. theta off Oregon may be influenced by many environmental factors. I will discuss the possible effects of physical processes and prey distribution.

Seasonal oceanographical changes off the Oregon coast have been described by several authors (Huyer, 1977; Huyer, Pillsbury and Smith, 1975; Huyer, Smith and Pillsbury 1974; Stevenson and Pattullo , 1966; Wyatt et al.,1967; Halpern, 1976). Two major oceanographic seasons are recognized: an upwelling season during the late fall and winter (Bakun, 1973). During coastal upwelling the alongshore component of surface flow is southward, as measured by moored current meters (Mooers, Collins and Smith, 1976), drogues (Stevenson and Pattullo, 1969) and drift bottles (Wyatt et al., 1972). An offshore component of the surface Ekman flow also occurs during upwelling (Smith, 1968). This advection of water offshore must be compensated by an onshore flow from deeper waters. Smith (1981) and Fonseca (1981) calculated that the volume of this deep onshore transport exceeds offshore surface flow. However, this flow has much lower velocities than the offshore transport (Huyer, 1976), and originates from depths of 200 - 380 m at 40 to 50 km offshore.

The winter or downwelling season is characterized by northward flow of surface waters along the coast (Wyatt et al., 1967; Bakun, 1973) with an onshore component of the surface Ekman flow.

The inshore and offshore abundances (no./m^2) of *D. theta* collected off Newport during the 1961 - 1967 period were compared with the upwelling index calculated by Bakun (1973) for 45°N 125°W. The offshore abundances of *D. theta* were not obviously correlated with the Bakun upwelling index, but inshore abundances show a negative relationship with the index (Fig. 20). Abundances of *D. theta* were highest during downwelling periods and lowest during upwelling periods. A regression model was calculated with the inshore abundances vs. the "downwelling index" which gave:

ABUNDANCE = -0.0180 + (-.0012) DOWNWELLING INDEX (r^2 = 0.541, n= 24).

An hypothesis to explain these results is based on the vertical migration pattern of *D. theta*. During the night it migrates to the surface waters and has its maximum abundance in the upper 50 m (Pearcy et al., 1977; Willis and Pearcy, 1980). Here it is most susceptible to advection by onshore Ekman transport, since the time spent in surface waters is maximal during the long winter nights, it will likely be transported farthest into neritic waters during this season.

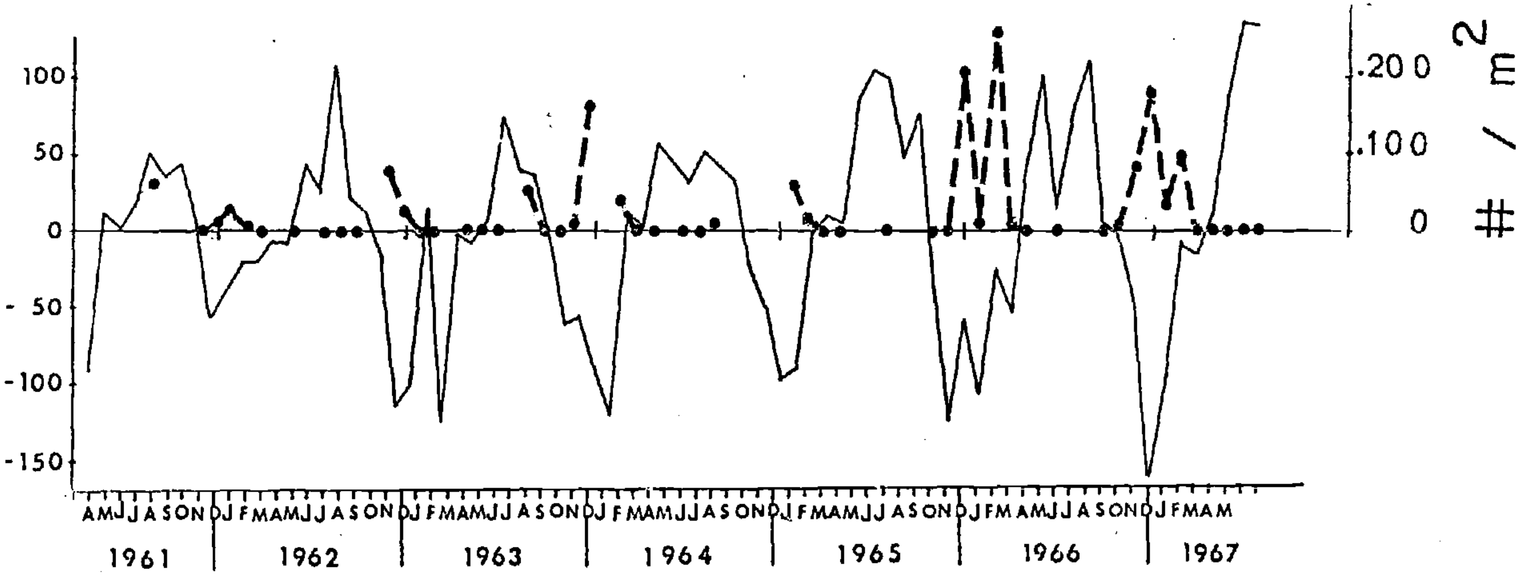

Fig. 20 . Upwelling index (Bakun, 1973) and inshore abundances ($\#/m^2$) of D.theta off Newport (1961 - 1967).

During the summer, D. theta spends most of the time at its daytime depths, where it will be affected mainly by deep currents that advect a large volume of water onshore to compensate the surface offshore transport of water. This could concentrate D. theta over the slope waters during the day. During the summer the largest abundances of D. theta were found in slope waters. Stations over the continental slope (depths of 200 to 1,800 m) were located 84 and 93 km (45 and 50 n.mi.) from shore off Newport and 28 and 46 km (15 and 25 n.mi.) from shore off Coos Bay and Astoria (depths of 200 to 900 m). Slope waters were much farther inshore off Coos Bay and Astoria because of the topography of the sea floor. Therefore, the peaks of abundance of D. theta during the summer months in all but the shallowest waters off Newport may be related to circulation prevailing during the upwelling. Relations with the physical processses have also been described by Parrish, Nelson and Bakun (1981) for commercilly important coastal species of fishes in the California Current. They found that reproductive strategies of these species show a pattern of correspondence to the major features of surface transport, i.e., coastal species in the Pacific Northwest having pelagic larvae tend to spawn during the winter when surface wind drift is generally directed to the coast rather than during the summer when Ekman transport is mainly offshore.

The distribution and abundance of D. theta may also be influenced by the distribution and abundances of their food items. Tyler and Pearcy (1975) determined that D. theta feeds primarily on the euphausiid Euphausia pacifica and the copepods Metridia lucens and Calanus spp. In terms of biomass euphausiids were the most abundant prey. Diet varied with size of fish. Euphausiids were most important for large fish but the frequency of occurrence of copepods in stomachs was highest for D. theta smaller than 30 mm. The smallest size group of fish analyzed (20 mm) only had copepods in their stomachs. Tyler (1970) reported larger numbers of euphausiids than copepods in stomachs of fish at NH-25, while at NH-45 the fish had more copepods in their stomachs.

The distribution and abundances of these two major prey taxa are known to vary with distance from shore and with seasons. Hebard (1966) found that the euphausiids, primarily E. pacifica, were most abundant inshore during late summer and fall at NH-15 and NH-25 (Newport hydro-stations, 15 and 25 n. mi. off Newport,Oregon) with maximum abundances at NH-25 where they comprised 57% of the numbers of zooplankton caught in 1-m diameter, .571 mm mesh nets. Euphausiid catches decreased drastically between NH-25 and NH-45. The copepods Metridia lucens and Calanus spp., on the other hand, generally increased in abundance with distance offshore reaching maximum concentrations at NH-65. Similar inshore-offshore trends in the distribution and abundances of euphausiids and copepods were reported by Laurs (1967) off

Brookings in Southern Oregon. Euphausiids were most abundant inshore (15 and 25 n.mi. from shore stations) and the copepods were most numerous offshore. All sizes of E. pacifica were much more abundant inshore than offshore waters with peaks in the abundance of furcilia during the fall off Newport, Oregon (Smiles and Pearcy, 1971).

These trends in the prey abundances correspond to the distribution of different sizes of D. theta. Small D. theta were most common in offshore waters (Table 4) where their most important prey, large copepods, were most abundant. Peaks in the abundances of D. theta occured during late summer and fall in inshore waters (Fig. 19). These fish were mainly larger age groups (Tables 4 and 5). The highest abundances of euphausiids, their preferred prey, were also most abundant during late summer and fall in the inshore region. Abundances of euphausiids and copepods were the lowest during the spring, in particular in the inshore region (Hebard, 1966), which coincides with low catches of D. theta in all three areas sampled.

The spawning season of D. theta was estimated from the length frequency information. During summer months 10-15 mm fish were caught in the IKMT. During the fall months 15-25 mm fish were found, and during the early winter of 1967 15-30 mm fish were observed. This information suggests that the spawning season off Oregon is during summer and fall. Larvae distribution information provided by Moser (pers. comm.) and Kendall and Clark (1982a,b) suggests that the spawning season of D. theta occurs during spring and early summer off northern California, and during the summer off Oregon (no data is available for larval distribution off Oregon for the fall).

The mean growth of D. theta based on the modal progressions of length frequency data can be followed to nearly 3 years with a mean length close to 70 mm. The estimated age from the otolith analysis tend to confirm this finding, although 70 mm fish could be a few months older. A few larger D. theta have been caught off Oregon, but none has been aged. This suggests that the life span of D. theta could be longer. These estimates are only valid for the area off Oregon, since Nafpaktitis (1978) and Wisner (1976) have reported latitudinal variations in growth. South of Cape Mendocino D. theta does not grow much larger than 60 mm while in the Gulf of Alaska 90 mm fish have been caught. Aron (1962) reported the capture of a 105 mm D. theta in the Bering Sea and also observed that the mean length increases with latitude.

The growth curve of D. theta estimated from otolith readings is compared with the growth curves of other myctophids in Fig. 21. According to this comparison the growth of D. theta is similar to that of Myctophum affine (Odate, 1966) and faster than Stenobrachius leucopsarus (Smoker and Pearcy, 1970). Benthosema glaciale (Halliday, 1970) seems to have

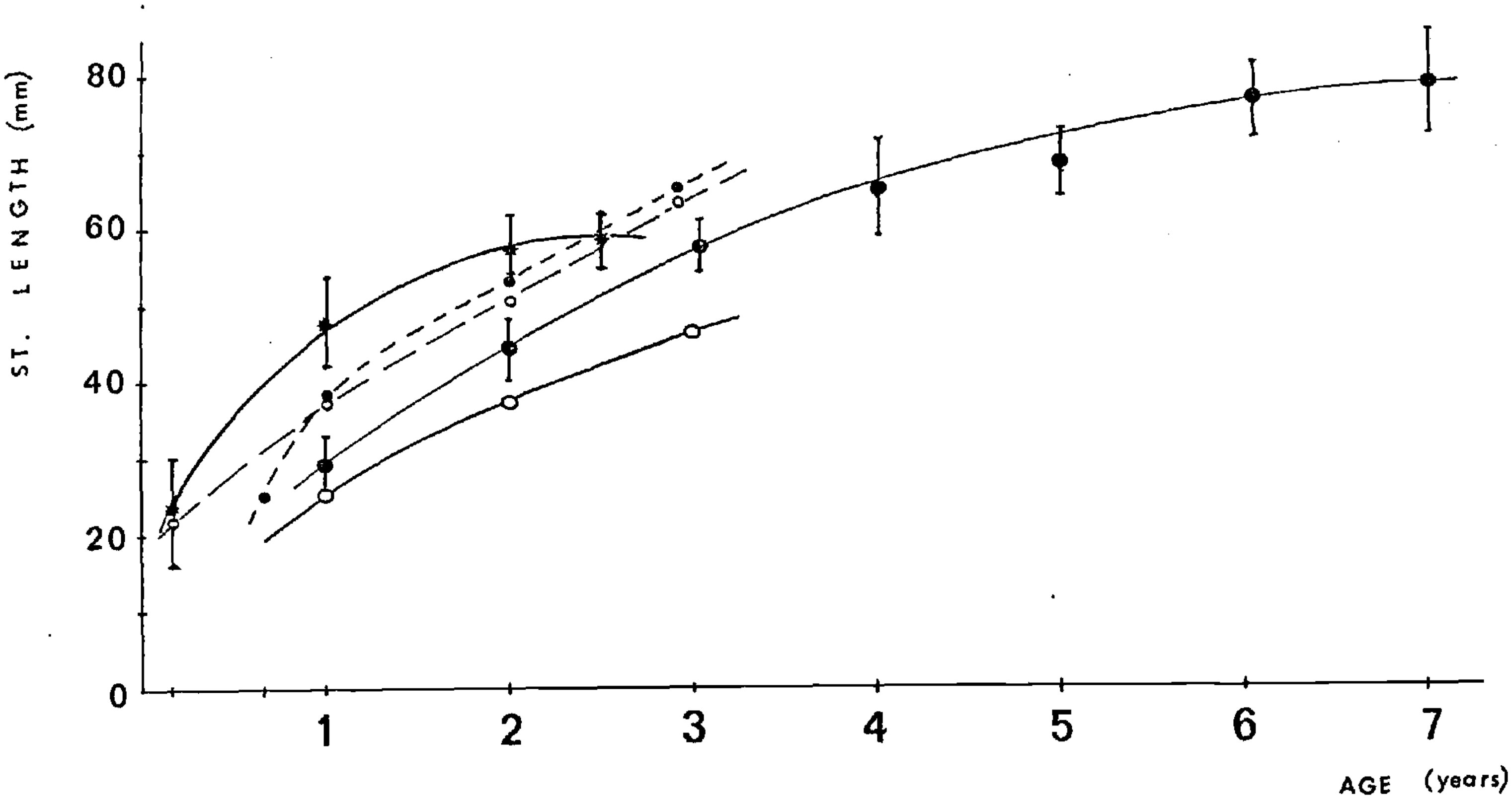

Fig. 21. Comparison of mean lengths vs. estimated age of:
D. *suborbitalis* (Go, Kawaguchi and Kusaka (1977a) (*).
Myctophum affine (Odate, 1966) (•).
D. *theta*. This study (∘).
S. *leucopsarus* (Smoker and Pearcy, 1970) (●).
B. *glaciale* (Halliday, 1970) (○).

the slowest growth of all these fishes. The study of Go, Kawaguchi and Kusaka (1977a) indicates that *Diaphus suborbitalis* has the fastest growth but also the shortest life span.

From the larval distribution information it seems that *D. theta* should be considered a transitional more than a Subarctic species with respect to spawning because no larvae have been caught north of 46°N (Waldron, 1972;Kendall and Clark, 1982a,b). This is also confirmed by Aron (1962) who did not find any *D. theta* larvae in the Bering Sea or Gulf of Alaska even though he captured adults of the species. The larval distribution is almost exclusively offshore, with very few specimens caught in the inshore region over the continental shelf.

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