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Early life history of weakfish *Cynoscion regalis* (Bloch and Schneider)

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EARLY LIFE HISTORY OF WEAKFISH *CYNOSCION REGALIS* (BLOCH AND SCHNEIDER)

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APPROVAL SHEET

This dissertation is submitted in partial fulfillment of

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ABSTRACT

Juvenile weakfish Cynoscion regalis, life history was studied in the York River estuary, Virginia. To verify daily aging methods of juvenile fish, both male and female adults were induced to spawn by injection of 200 IU Human chorionic gonadotropin/Kg wet weight. Subsequent larval and juvenile fish were reared up to 275 days with wild plankton and a daily rotating diet of squid, liver, Anchoa mitchilli, and Menidia menidia. Otoliths and scales were examined for daily microincrements patterns. Otolith ring counts were highly variable (31% varied by > 15% among 3 counts). Two problems were evident: 1) Microincrements frequently split to form two increments; and 2) Otoliths from a size series of fish (6.12-13.1 mm) indicated that weakfish otoliths grew by bud formation rather than concentric deposition. Scale circuli showed little variation between counts (99.5% of 2 counts from an individual scale were the same). Daily scale deposition was suggested by rearing to 100 days, after which ring deposition was less than daily, however further research is needed because only one fish was reared past 25 days. The advantages of scale circuli counting over otolith increment counting were increased precision and ease of preparation.

Field samples were collected weekly from the York River channel, at night using a 4.9 m, 1.5 mm cod end, trawl, during the weakfish nursery period (Aug-Oct 1983). The new technique of daily aging by scales, was applied to 845 of 922 weakfish collected. Counts ranged from 3 to 100 circuli/scale. Three cohorts were defined from the 1983 0-age fish. Growth rates estimated from scales (0.76 - 1.13 mm/d) were similar to those from length frequencies (1.0-1.2mm/d). Analysis of covariance showed a significant difference (0.05 level) in growth rates among cohorts and among stations, but third order interactions (station, cohort, growth rate) were not detected. Mortality/ migration rates estimated from decline in mean catch were significantly different between cohorts 1 and 2 (0.05 level, t-test). Weakfish were first abundant as new recruits at the river mouth, and moved upriver as they grew. In the fall a reverse migration occurred. Birthdate frequency by station and date indicated that different cohorts used different areas of the York River.

EARLY LIFE HISTORY OF WEAKFISH *CYNOSCION REGALIS* (BLOCH AND SCHNEIDER)

LITERATURE REVIEW

Weakfish Cynoscion regalis, are found along the Atlantic coast of the United States from southern Florida to Massachusetts, straying occasionally to Nova Scotia (Hildebrand and Schroeder, 1928; Bigelow and Schroeder, 1953; Leim and Scott, 1966; Chao and Musick, 1977). The capture and documentation of two adult weakfish (266 and 298 mm SL) off Marco Island, Florida, validate the occurrence of this species in the Gulf of Mexico (Weinstein and Yerger, 1976).

Weakfish are important as a recreational fish and a commercial food fish. They contribute the most to the total value of United States sciaenid landings followed by croaker Micropogonias undulatus, spotted seatrout C. nebulosus, spot Leiostomus xanthurus, and red drum Sciaenops ocellatus. Commercial landings of weakfish were valued at 8.8 million dollars in 1981 (Mercer, 1983). The recreational fishery also probably makes a substantial but unknown contribution to the food fish market (for review see: McHugh,1977; Wilk, 1979; Cato, 1981; Mercer, 1983).

Historically, populations of weakfish have fluctuated widely (Merriner, 1973; McHugh, 1980; Mercer, 1983). At present weakfish are abundant, although there has been a slight decline in landings from a peak in 1980. Weakfish have extremely high fecundities. Merriner (1976) reported that a 500 mm total length female could produce as many as two-million eggs, while Shepherd (1982) found an average annual fecundity of 300,000 eggs/500 mm TL female. Obviously not all of these

will survive and, at some point, or over several "critical periods" mass mortalities must occur. These high mortalities are believed to occur mainly during the first few months of life (Gulland, 1965; Cushing, 1974, 1976; May, 1974; Hunter, 1976).

Spawning of weakfish occurs in the near-shore and estuarine zones along the Atlantic coast (Bigelow and Schroeder, 1953; Harmic, 1958; Massmaun, 1963; Merriner, 1976; Olney, 1983). Merriner (1973) and Massmann (1963) reported a protracted spawning season and possible multiple spawning occurs in some females. Two distinct size groups of young-of-the-year were found in fall collections from Chesapeake Bay, 45 and 85mm, and Delaware Bay, 30-40 and 110-130 (Massmann 1963; Thomas, 1971). With protracted spawning, differential mortality or critical periods may occur during the first summer with particular spawns showing better survival than others.

A new technique that enables one to age larval and juvenile fishes can be used to identify differential mortality or critical periods during the first summer of life from a field survey. Daily growth increments in the sagittal otoliths of teleost fishes were first described by Pannella (1971). Since then, numerous studies have documented daily increments in the otoliths of a wide variety of marine and freshwater fishes (Pannella, 1974; Wilson and Larkin, 1980; Uchiyama and Struhsaker, 1981). Studies of both laboratory and wild populations of larval fishes show high correlation between the number of growth increments and the age in days since hatching, yolk absorption, or first feeding (Brothers et al., 1976; Methot and Kramer, 1979; Wilson and Larkin, 1980; Tanaka et al., 1981). The formation of daily increments is linked to light-dark periods, and is independent of time and frequency

of feedings (Taubert and Coble, 1977; Tanaka et al., 1981).

The best way to evaluate the early life history of fishes is through growth rates, because growth integrates the variability in food and other environmental conditions. By knowing age from otolith increments, and standard length, growth rates can be estimated. A suggested scenario is that young weakfish first encounter the heaviest mortality during the first months of life in the lower estuary. This hypothesis would operate through a combination of starvation and predation, where predation intensity is partially controlled by the condition of the larvae, which in turn is controlled by the larva's nutritional state (Rothschild and Rooth, 1982). Ideally, faster growing weakfish will characterize the year class at the end of the summer because these are the survivors that obtained adequate nutrition and escaped predators.

The objectives of the present study were to: determine if daily aging was possible for juvenile weakfish from the York River, and to determine birthdate distribution and growth rates, for juvenile weakfish from the York River, Virginia. In order to achieve these objectives three areas of study were needed. First, I needed a supply of young weakfish to validate daily aging methods. This was accomplished by spawning captive adult fish by injection of Human chorionic gonadotropin, and is the subject of chapter 1. Second, after spawning and rearing techniques were established, validation of daily increments in otoliths and scales was attempted, and is the subject of chapter 2. Third, after a tentative daily aging method by scales was developed, this method was applied to field collected fish from the York River, VA., and is the subject of chapter 3.

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CHAPTER 1

HORMONE INDUCED SPAWNING OF WEAKFISH

INTRODUCTION

Induced spawning of captive finfish is a well known technique that can produce eggs and larvae on demand, and has been applied to a variety of finfish including: winter flounder Pseudopleuronectes americanus (Smigielski 1975); southern flounder Paralichthys lethostigma (Lasswell et al. 1978); walleye Stizostedion vitreum (Hearn 1980); Atlantic sturgeon Acipenser oxyrhynchus (Smith et al. 1980); Gulf menhaden Brevoortia patronus (Hettler 1983); and black sea bass Centropristis striata (Tucker 1984). Although other sciaenid species, Cynoscion nebulosus (Colura 1974; Fable et al. 1978; Taniguchi 1982; Porter and Maciorowski 1984) and Sciaenops ocellatus (Arnold et al. 1979), have been induced to spawn in the laboratory, information on the weakfish Cynoscion regalis, is lacking.

Fish pituitary extract has been identified as a superior ovulation inducing agent (Smigielski 1975; Lasswell et al. 1978), but its activity can vary (Harvey and Hoar 1979). The present study examines the use of human chorionic gonadotropin (HCG) for induced spawning of weakfish, an inexpensive ($30/10000 IU) readily available inducing agent that has been used in other species with relative success (Stevens 1966; Hearn 1980; Tucker 1984).

MATERIALS AND METHODS

Weakfish were collected from commercial pound nets in the York River estuary, Virginia, in the spring and fall 1984, and spring 1985. Because of the relatively slow retrieval method with pound nets, 100% survival was achieved for all fish brought back to the laboratory. After capture fish were initially placed in 860 L circular flow through seawater systems. After a five day acclimation period fish were placed in 1060 L recirculating rectangular spawning tanks. The sediments of the spawning tanks were 10 cm deep oyster-shell air lift filters, and 2 kg carbon-wool filters were used for additional removal of dissolved organics.

Temperature was maintained within $\pm$1 C for each spawning trial, using a controlled temperature room and three submersible 250 watt thermostat controlled heaters. Salinity was maintained by addition of seawater or artificial sea salts. Induced spawning was attempted at temperatures ranging from 18.5 to 25.0 C, and salinities ranging from 19.8 to 25.5 ppt, in July 1984, February and March 1985, and July 1985. Photoperiod during injection of HCG was maintained at 16.2 hours light/ 7.8 hours dark in all trials. However, in an attempt to bring fish into ripe condition outside their normal spawning period (April to August, Merriner 1976) fish captured in September 1984, were exposed to a year cycle of photoperiod in 150 days, at constant temperature (18.5 C), and

HCG induced spawning attempted in February and March 1985. A rubber fishing net was used to remove weakfish from spawning tanks for HCG injection, after it was determined nylon netting severely damaged the fish. Prior to hormone injection, fish were anesthetized in a 75 L tank filled with a 50 mg MS-222/L seawater solution. Deep anesthesia was achieved in 2-3 minutes, as indicated by no movement in gills. A 50 mg/L concentration of MS-222 can be fatal, therefore, weakfish must be closely monitored and removed immediately after gill movement stops. Fish were injected with HCG in the epaxial muscles proximal to the dorsal fin, via a tuberculin syringe at a dose of 200 IU/Kg wet weight, with a second dose administered after 24 hours. It is difficult to distinguish the sex of weakfish through external morphology and catheterization was unsuccessful using 1.27 mm intramedic polyethylene tubing (Ross 1984). However, selection of males was possible at the time of collection because only males produce sound (Merriner 1976).

RESULTS AND DISCUSSION

A total of 23 weakfish were injected with HCG. In July 1984, five females and three males, 596 g mean wet weight, spawned within 24 hours of the second HCG injection, at 19.8 ppt salinity and 25.0 C. A similar attempt in July 1985, with three females and two males, 486 g mean wet weight, 25.0 ppt salinity and 23.4 C, also produced fertilized eggs within 24 hours of the second injection. In addition, the July '85 group spawned a second time approximately 96 hours after the second injection without additional HCG (Table 1).

The attempt to cycle fish through a full year photoperiod in 150 days and spawn weakfish outside their normal range was unsuccessful. On 16 February 1985, at 24.6 ppt salinity and 18.5 C, injections of HCG failed to produce fertilized eggs using three females and two males (669 g mean wet weight). The temperature was raised to 22.8 C by 14 March 1985, and another group of three females and two males (612 g mean wet weight) failed to spawn after HCG injections. It is difficult to determine the reason for no spawning, and further research is needed concerning temperature effects (Lee and Hirano 1985), and loss of HCG activity (activity drops significantly after 30 days, unpublished Cresent Chem. Co.).

In conclusion, since summer trials produced viable eggs, HCG is apparently suited for use with weakfish. Larval weakfish production by HCG induced spawning has the advantage of convenient timing for rearing

experiments, compared with photoperiod manipulation where egg production is highly unpredictable.

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TABLE 1: Hormone-induced spawning of weakfish Cynoscion regalis, by injection of 200 IU HCG/ Kg wet weight.

Table 1. Hormone-induced spawning of weakfish Cynoscion regalis, by injection of 200 IU HCG/ Kg wet weight.

Trial	N $\bar{x}$ wt g	1-inject date hour	2-inject date hour	spawned eggs date hour	hatch date hour	sal ppt	temp C
1	2 526	22Jul84 1200	23Jul84 1424	24Jul84 0900	no hatch	19.8	25.0
2	6 665	23Jul84 1600	24Jul84 1724	25Jul84 1000	27Jul84 0830	19.8	25.0
3	5 669	16Feb85 1830	17Feb85 1840	no eggs		24.6	18.5
4	5 612	14Mar85 1430	15Mar85 1410	no eggs		25.5	22.8
5	5 486	17Jul85 1240	18Jul85 1715	19Jul85 0900	20Jul85 1230	25.0	23.4
"	"	no injection	no injection	22Jul85 1050	23Jul85 0800	25.0	23.4

CHAPTER 2

DAILY AGING OF JUVENILE WEAKFISH

INTRODUCTION

The study of early life history stages of fishes is critical in understanding fluctuations in year class strength (Hjort 1914; May 1974; Rothschild and Rooth 1982). Growth of young fishes is one parameter that may integrate most other factors, i.e., prey abundance, predation, and environment (Werner and Gilliam 1984; Weatherley and Gill 1987), but until recently it has been mainly studied in the laboratory (Houde 1977; Knutsen and Tilseth 1985; Kiorboe and Munk 1986) or by length frequency analysis of field collection (Kumagai et al. 1985). A recent technique, first published by Pannella (1971), is that microscopic daily rings can be counted on the otoliths of fish, and growth rates of field collected fish determined. Since then, there have been a number of studies using this technique (see reviews: Campana and Neilson 1985; Jones 1986), and daily otolith aging has been successful for many species from different habitats, for example: the blue head wrasse Thalassoma bifasciatum, from tropical reef areas (Victor, 1982); the Starry flounder Platichthys stellatus, from the northeast Pacific coast (Campana and Neilson 1982); and two abyssal macrourids Coryphaenoides armatus, and C. yaquinae (Wilson 1988). Also, published light microscopy and SEM photographs suggest relative ease in discerning rings (Tabeta et al. 1987; Kendall et al. 1987; Nishimura and Yamada 1988).

However, the deposition of clearly discernable daily increments in fishes is not universal and some species have multiple primordia

(Neilson et al. 1985); bands may be too close to resolve with a light microscope (Campana et al. 1987); or rings are not apparent for some time after hatching (Lough et al. 1982). In addition, rereading the same otolith is highly variable in some species, and Rice et al., (1985) suggest a statistical power analysis before concluding rings are daily.

These previous studies suggest that daily aging in otoliths depends on the species studied; and because daily aging has not been previously attempted with weakfish Cynoscion regalis, the present work examines the microincrements in weakfish otoliths. In addition, a new method is tested: daily aging by counting scale circuli.

MATERIALS AND METHODS

Adult weakfish were collected from commercial pound nets in spring and fall 1984, and spring 1985-86, York River Estuary, Virginia. Holding facilities and spawning techniques are described in Chapter 1. After hatching, weakfish larvae were reared on wild plankton collected daily with a plankton net (63 um, 0.5 m). Plankton were sorted between 53-505 um, and fed at concentrations of 500-5000 wild plankton/l. Weakfish larvae were stored in 70% ethanol, or 4% formalin-NaAcetate, and preservatives were changed in 24 hr. Standard lengths (SL) of live larvae up to 20 days (anesthetized with MS-222) were recorded with a stage micrometer under a dissecting microscope to the nearest 0.01 mm, and otoliths removed for examination by light and scanning electron microscopy according to Haake et al., (1982). To determine circuli variation among different locations of the same fish at least 13 scales were removed from several different locations, on York River weakfish of three different sizes. All scales were fixed on a glass slide with methacrylate (Flo texx, Lerner Laboratories), and glass cover slip.

To provide a known age scale series one weakfish was kept alive from the above group, and fed ad libitum for 275 days with a rotating daily diet of squid, beef liver, Menidia menidia, and Anchoa mitchilli. After anesthetizing with a solution of 50 mg MS-222/L seawater, four or more scales were removed just below the mid-body lateral line curve at 84, 107, 148, 170, 200, 228, and 275 days after hatching.

Otolith SEM pictures were taken using Polaroid polarpan 4x5 land film 52 (200-500X), but SEM counts were made at 5000X. Light microscope otolith pictures were taken with Kodachrome gold 400 film (125X), but counts were made at 1250X. Development of weakfish otoliths was examined through light microscope pictures of a size series (6.12-13.10 mm larval SL). All subsequent counting of increments (except SEM) were made with a Zeiss Universal microscope equipped with a Hitachi DK 5053 color video camera, which projected the scale image onto a high resolution monitor.

Sagittal sections of otoliths were read three times along a transect 40 degrees above the anterior posterior diameter, from the primordium to the perimeter, and if counts were not within 10% agreement they were not used in regressions. Scale increments were counted along a central radius on the growing or internal side, and 2 or 3 readings were made to verify the initial count. Standard lengths of juvenile fish were measured to the nearest 0.1 mm with a mitutoyo caliper.

Standard length at scale formation was estimated by a linear regression of SL on scale circuli count, from field collected fish (see Chapter 3 for collection methods). Age at first scale formation was then estimated from the relation of known age on SL of the wild plankton reared fish.

Validation of scale aging was attempted in eight older field collected weakfish (>80 mm SL) by immersion in 0.4 mg/l tetracycline hydrochloride seawater (25 ppt) for 24 hrs (Campana and Neilson 1982). At least five LL scales were removed at 1, 5, 26, 55, 77, 107, 135, 166, and 196 days after tetracycline exposure, and the number of circuli after marking counted. Marked weakfish were fed with the same frequency

and diet as the reared fish.

RESULTS

Otolith reading of microscopic increments was highly variable: 31% of otoliths (N=52) varied among counts by more than 15% after three counts. Scanning electron microscopy photographs of otoliths, showed that count variation often results from increments splitting into two or more rings: i.e., concentric rings are difficult to trace because they often divide into two or more rings (Fig. 2). Light microscope counting compared to SEM counting failed to increase precision, r^2= 0.66 and 0.21 respectively (Fig's. 3, 4).

One reason for the low r^2 above was the difficulty in deciding what constituted a ring and what did not (Fig. 5). Another problem with weakfish otoliths suggested from a size series of light microscopy photographs (Fig's. 5-8), is that weakfish otoliths may not grow in a concentric pattern but through a series of bud formations. Figure 5, shows a weakfish otolith (6.12 mm SL) that appears to deposit rings concentrically, but soon after, otoliths appear to grow through bud formation (6.87 mm SL; Fig. 6). Figure 7, shows a larger otolith (9.7 mm SL) with 3 bud formations on the bottom and right side of the photograph. When superimposed the bud formations of figure 7 fit on the perimeter of figure 6's otolith, though they were from different larvae. Figure 8, shows buds on a section of otolith from a 13.1 mm SL fish.

Scale circuli from juvenile weakfish showed greater precision and ease in counting compared to otoliths (Fig. 9), however circuli counts from different locations from a single fish showed considerable variation (Fig. 10). All three sizes of fish showed relatively high counts from lateral line scales and little variation within scales taken from a particular location. Because scales were frequently lost due to trawl abrasion from ventral and caudal areas, and high counts from the lateral line area, all scales used to age weakfish were taken from the latter area.. In 3562 out of 3580 field collected scales (Chapter 3) rereading gave the same ciculi count. A regression of SL on circuli number estimated the size at scale formation as 14.3 mm (N=845; Fig. 11). This length, 14.3 mm, was used to estimate the age at which weakfish first formed scales from the known age on standard length quadratic regression. Weakfish were approximately 26.1 days old when the first scale was formed (N=548; Fig. 12). The 26.1 day estimate was then used as a single count, along with circuli counts at known age, from the juvenile fish that was raised to 275 days (Fig. 13). Visual inspection of the quadratic regression showed that rings were formed approximately daily from age 26-107 days, while subsequent ring deposition was less than daily. However, a curvilinear relation is apparent from 107 to 150 days but the quadratic model can be used to estimate age for this period, after which the curve levels out and cannot be used for older fish.

Tetracycline marking of scale circuli in older juvenile fish left a clear mark in scales viewed under 50 watt, U.V. excitation. However, ring deposition was not daily after tetracycline marks formed (Fig. 14). This confirmed results with the reared fish, i.e., at approximately 150

days of age or 140 mm SL, scale counts approached an asymptote. Another relation that may be used to age juvenile fish is known age on standard length, but fish grow at different rates and this method should be used with caution (Fig. 15).

DISCUSSION

Microscopic increments in otoliths were also reported for C. jamaicensis a congener of the weakfish, (Pannella 1974). However, Pannella's (1974) SEM photographs of C. jamaicensis, show the same splitting of otolith increments that contributed to low precision for C. regalis. Using counts of low precision is especially difficult when trying to compare growth rates over time and space (Rice et al. 1985). A few other species have also presented problems with daily otolith aging: Clupea harengus ring deposition is not daily (Geffen 1986; Lough et al. 1982), and events such as feeding more than once a day may cause increment production above 1/d as reported in chinook salmon Oncorhynchus tshawytscha (Neilson and Geen 1985). Campana et al. (1987) suggested that previous reports of less than daily increment deposition results from the limited resolution with light microscopes, and use of SEM could correct this problem. Scanning electron microscopy failed to increase precision in weakfish, because counting difficulty is related to growth patterns, i.e., budding rather than concentric otolith growth and splitting of increments (Fig's 2; 5-8).

The second method of daily aging, counting scale circuli, has not been previously reported for several reasons: 1) otoliths have been successful; 2) the delay in formation of scales after hatching; and 3) because too few rings are apparent before the first annuli in most fish (Sire 1986; Doyle et al. 1987). However, in two congeners C. nothus and

C. arenarius, scale photographs show more than 100 circuli before the first annuli indicating the method may work for other Cynoscion spp. (Shlossman and Chittenden 1981; DeVries and Chittenden 1982). For most fish, scale counting has the advantages of precision, and ease in preparation. Essig and Cole (1986) suggested that the greatest limiting factor in using otoliths was the time and effort needed to age fish, i.e., otolith removal requires dissection, some type of mounting, polishing and grinding. Typically, the required effort has resulted in low sample sizes, for example: N=54 over 3 years for juvenile chinook salmon (Neilson and Geen 1986). My work shows that large numbers of fish can be aged by counting scale circuli. However, otoliths have the great advantage of early development and are usually present in the yolk sac stage, where scales are formed later (Campana and Neilson 1985; Jones 1986).

The delay in circuli deposition in scales is difficult to overcome except through rearing experiments, but this delay is not limited to scales: Lough et al. (1982) found that larval Atlantic herring Clupea harengus, possibly required as many as 22 days to form the first three otolith increments. The difficulty in aging older juvenile weakfish (>150 d age; 140 mm) by scales can also be a problem with otoliths, for example Jenkins (1987) could not age fish past 35 days, in two species of flounder Rhomboselea tapirina and Ammotretis rostratus.

The major problem with the present study is that only one known-age weakfish was reared through the juvenile stage (275 days). This problem can only be corrected through more study. Another potential criticism is that the x-intercept was not estimated from the same fish. This data point is probably accurate however, because 845 field collected fish

were used to estimate the size of first scale formation, and this size was then used in a known age on standard length regression with 545 laboratory reared fish.

In summary, microincrements of larval and juvenile fish otoliths have been used to estimate age since the early 1970's (Campana and Neilson 1985; Jones 1986). Recently the approach was extended to the statoliths of squid (Hurley et al. 1985) and later to larval sea scallops Placopecten magellanicus (Hurley et al. 1987). The present study shows that aging of juvenile weakfish by otoliths is difficult due to splitting of increments, and otolith growth by bud formations. However, a new technique is presented that suggests daily aging of weakfish can be accomplished by counting scale circuli. Advantages of circuli counting for weakfish are a high degree of precision between counts, and ease of preparation allowing large numbers of fish to be processed. One point that is critical to scale aging techniques that needs further work, is whether or not circulus deposition is independent of growth rate. There is some evidence that suggests this may be the case, where growth has been correlated with spacing between circuli on a daily basis (Healey 1982; Sire 1986; Doyle et al 1987). Assuming growth is independent of circuli deposition in juvenile weakfish, the same informative survivorship studies that have been accomplished with otoliths of Northern anchovy Engraulis mordax (Methot 1983), Atlantic silverside Menidia menidia (Barkman and Bengtson 1987) and American shad Alosa sapidissima (Crecco and Savoy 1985), may be carried out with the present species.

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Figure 1. Juvenile weakfish Cynoscion regalis, showing the location of scale collection: ad=anterior dorsal, p=pectoral, av=anterior ventral, md=mid-dorsal, ll=just below lateral line curve, mv=mid-ventral, cd=caudal dorsal, cv=caudal ventral.

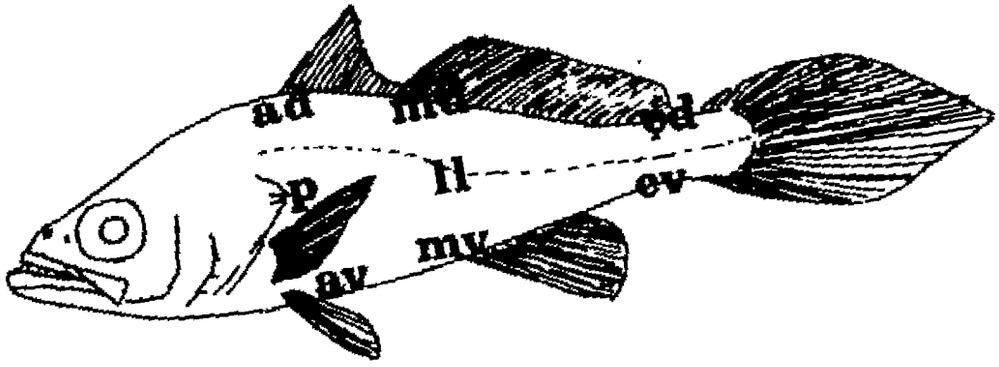

ad
md
pd
p
ll
ev
mv
av

Figure 2. Scanning electron microscope pictures of weakfish Cynoscion regalis, otoliths, showing microincrements. Arrow depicts section where increment splitting occurs.

Figure 3. Otolith ring count on standard length regression, counted under light microscope for weakfish, Cynoscion regalis, in the York River. Stations: 1 = 0 km mouth; 4= 45 km upriver. r^2 = 0.658, Y = 0.80X + 25.2.

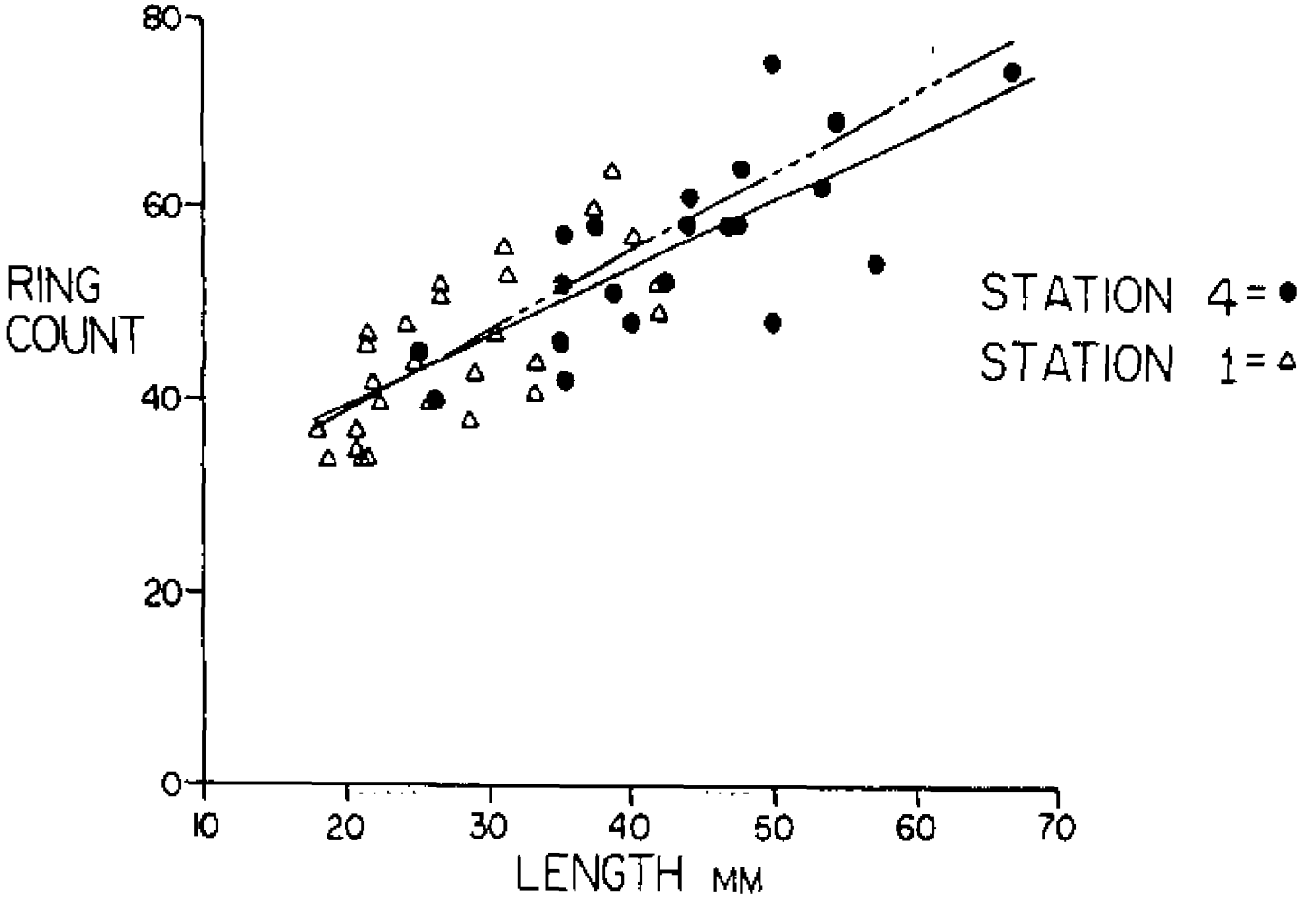

80
60
40
20
0
RING
COUNT
10
20
30
40
50
60
70
LENGTH MM
STATION 4 = ●
STATION 1 = △

Figure 4. Otolith daily age on standard length regression, from SEM photographs, for weakfish Cynoscion regalis, in the York River. $r^2 = 0.21$, $Y = 0.28X + 40.2$.

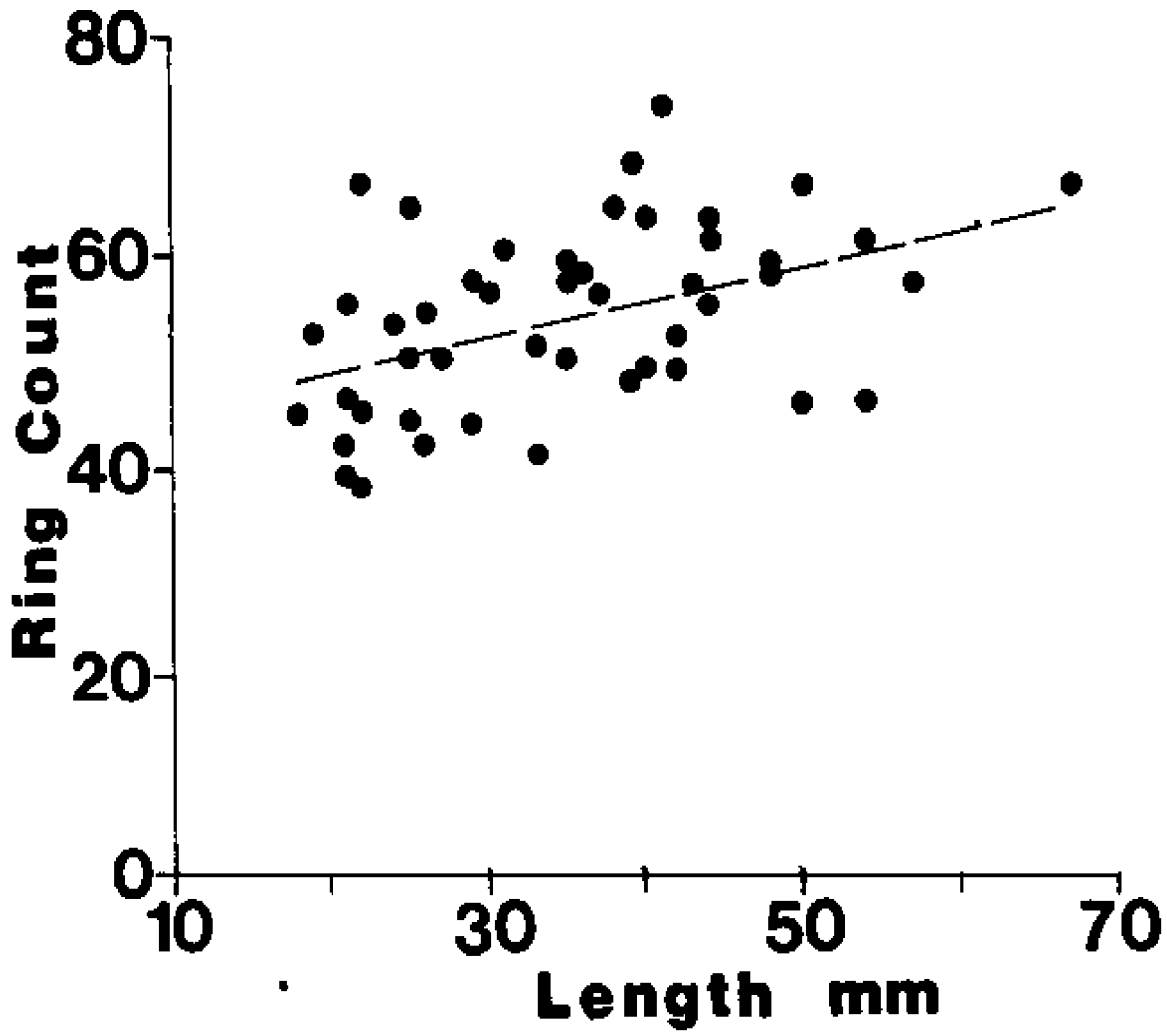

80
60
40
20
0
Ring Count
10
30
50
70
Length mm

Figure 5. Otolith from a reared weakfish larva before bud formation, 6.10 mm standard length, photograph taken at 200X. Scale: maximum diameter of otolith = 0.67 mm.

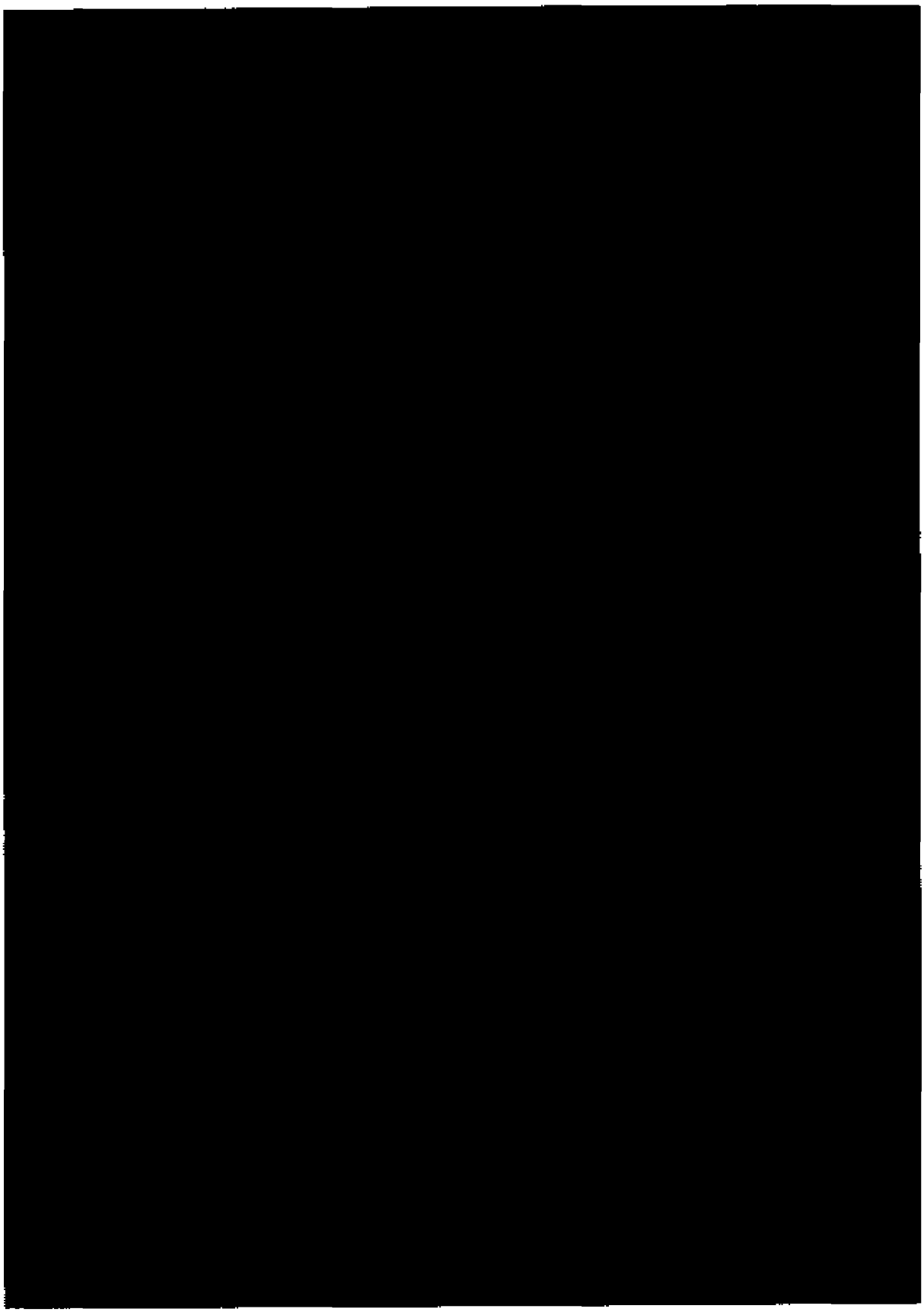


Figure 6. Otolith from a reared weakfish larva, 6.87 mm standard length, photograph taken at 200X. Scale: maximum diameter of otolith = 0.72 mm. Arrow shows a single bud formation on the edge of the otolith.

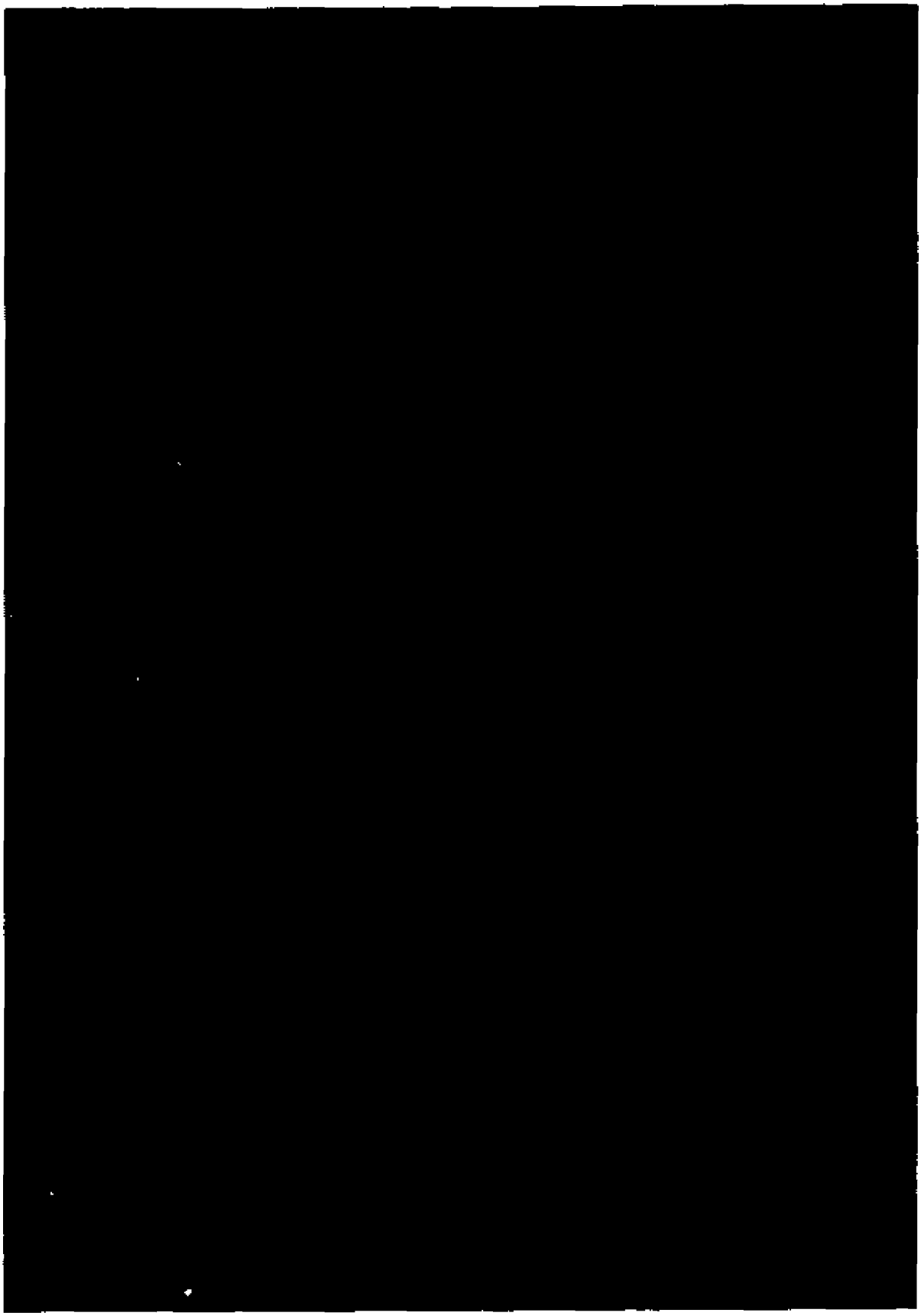


Figure 7. Otolith from a reared weakfish larva, 9.70 mm standard length, photograph taken at 125X. Scale: maximum diameter of otolith = 1.31 mm. Arrows show three bud formation on the edge of the otolith.

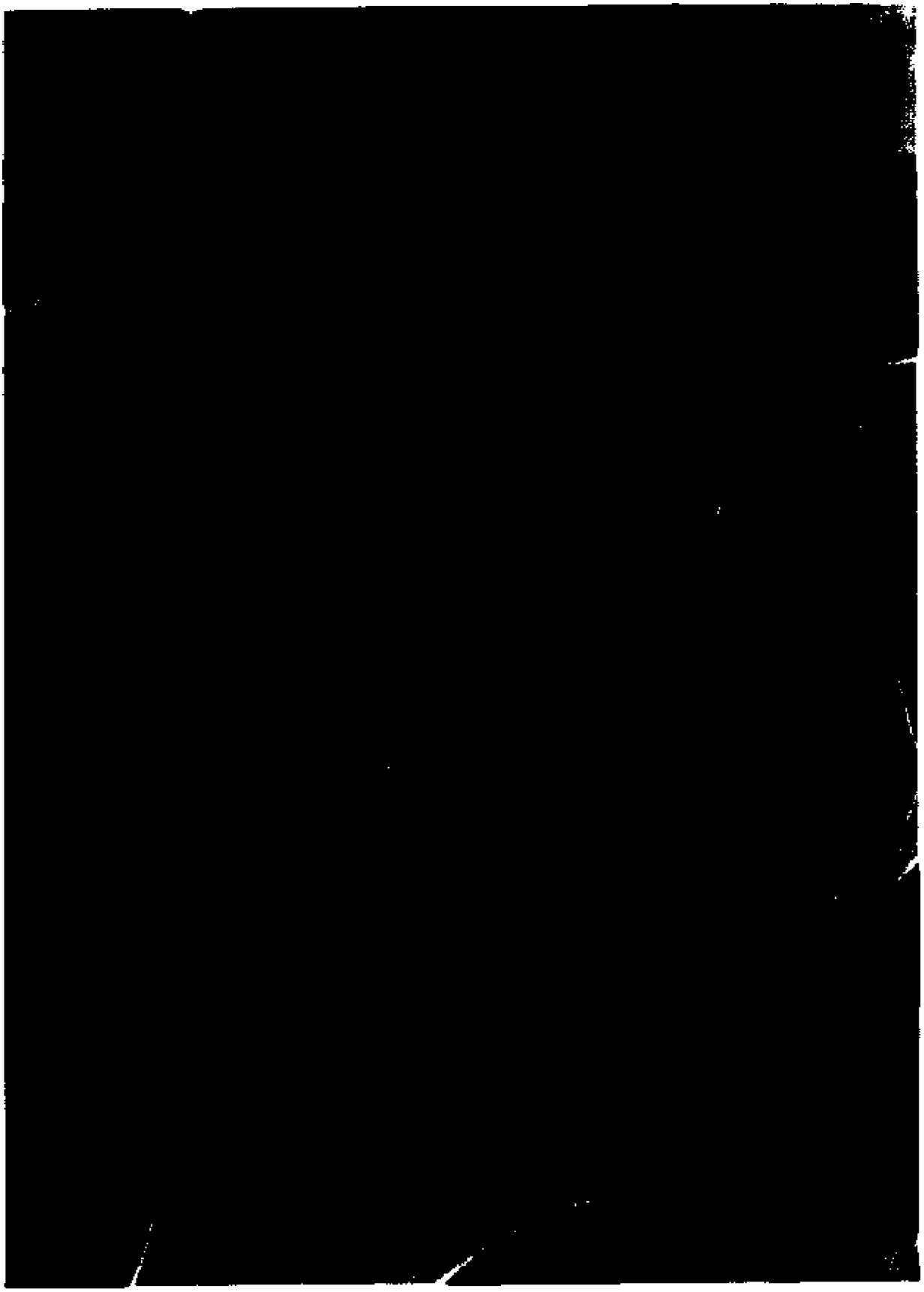


Figure 8. Otolith from a reared weakfish larva, 13.10 mm standard length, photograph taken at 125x. Scale: maximum diameter of otolith = 1.45 mm. (whole otolith not shown). Arrow shows bud formation on the edge of the otolith

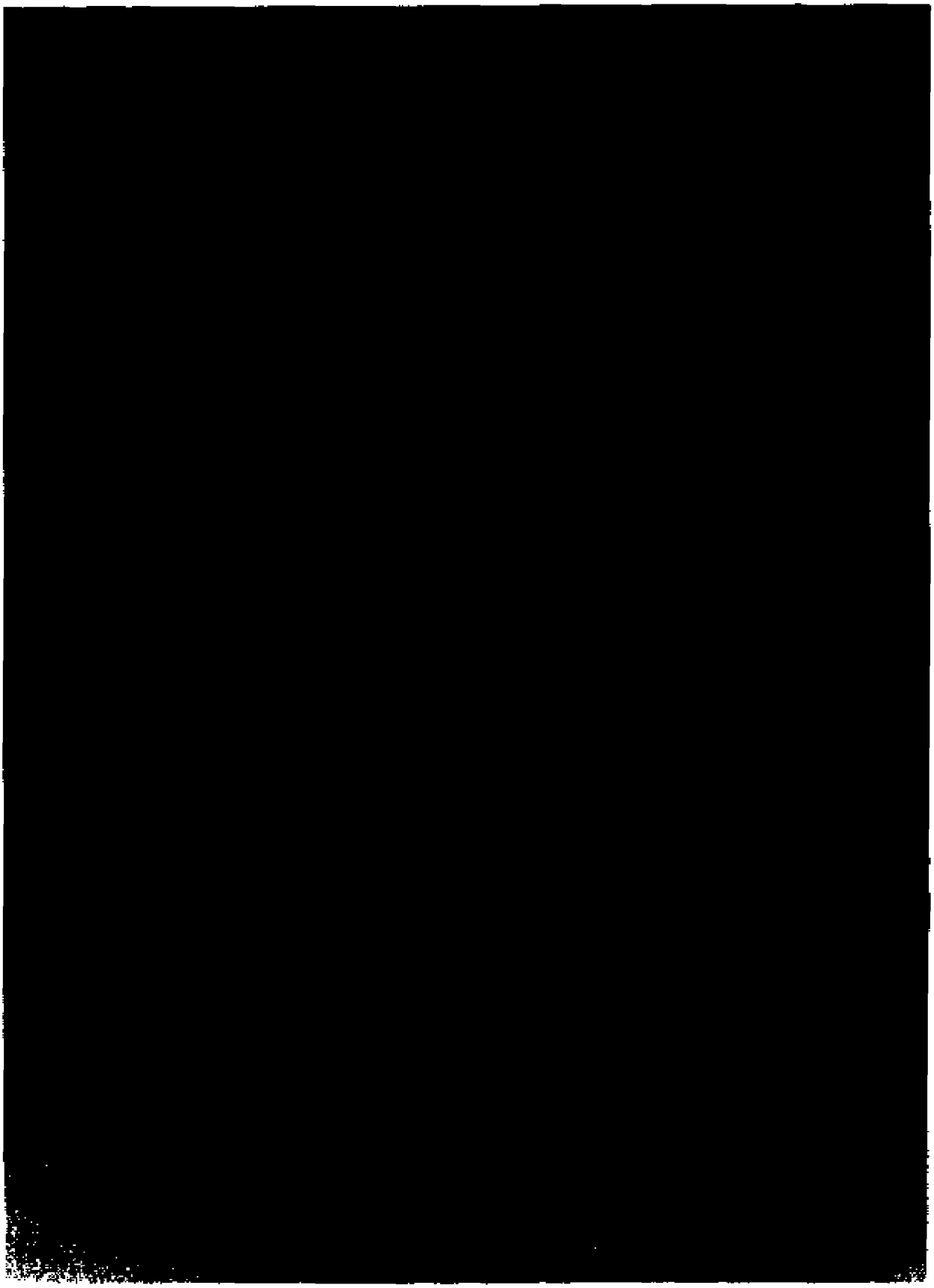


Figure 9. Scale circuli of weakfish, photograph taken at 125X. Arrow depicts counting radius (0.5 mm) from center circuli to perimeter along growing side.

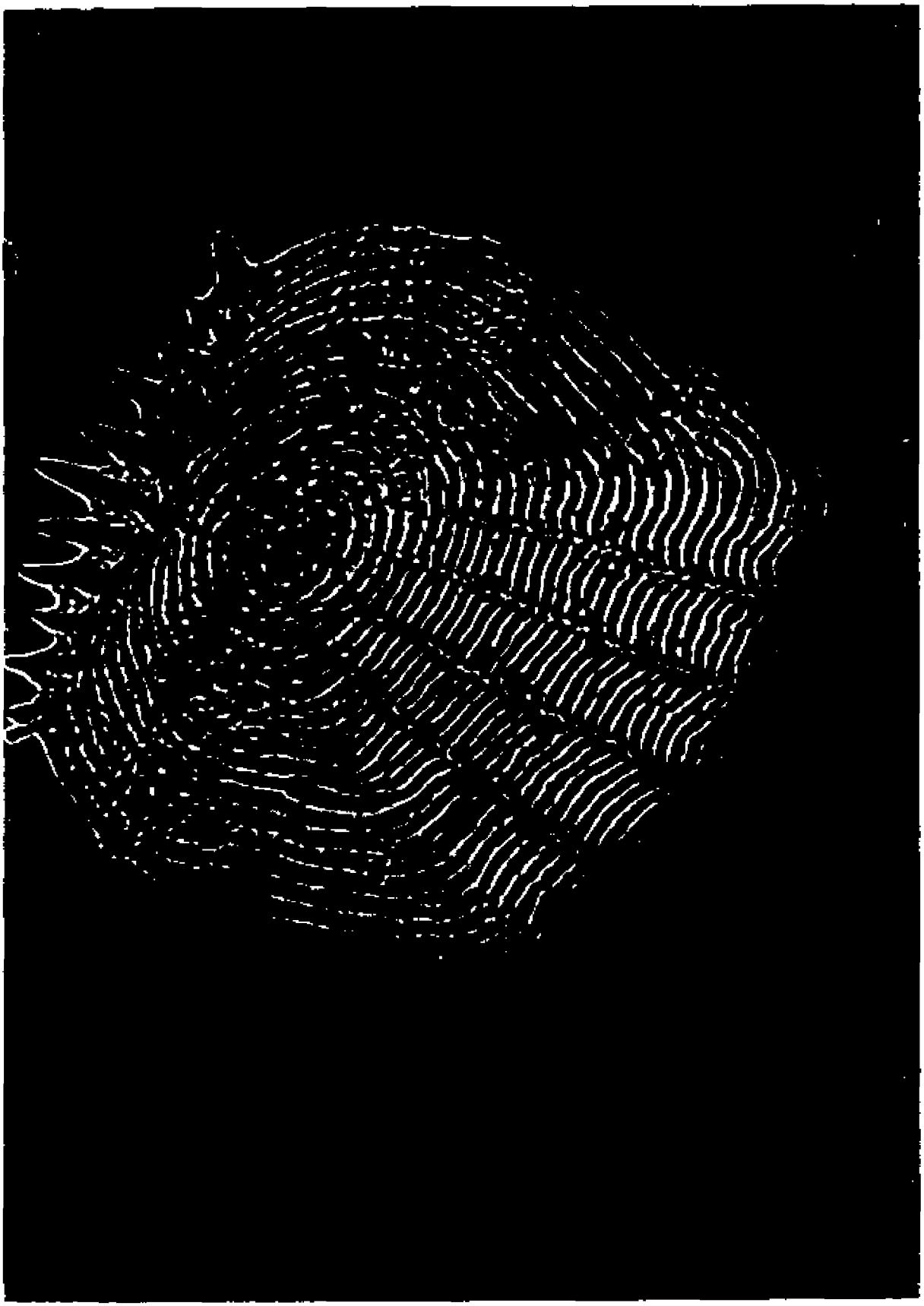


Figure 10. Scale circuli count from different locations from three different size weakfish. Scale types: P=pectoral; AD=anterior dorsal; AV=anterior ventral; CD=caudal dorsal; CV=caudal ventral; LL=just below the lateral line curve; MD=mid dorsal; MV=mid ventral. Bars are means ± 95% confidence intervals.

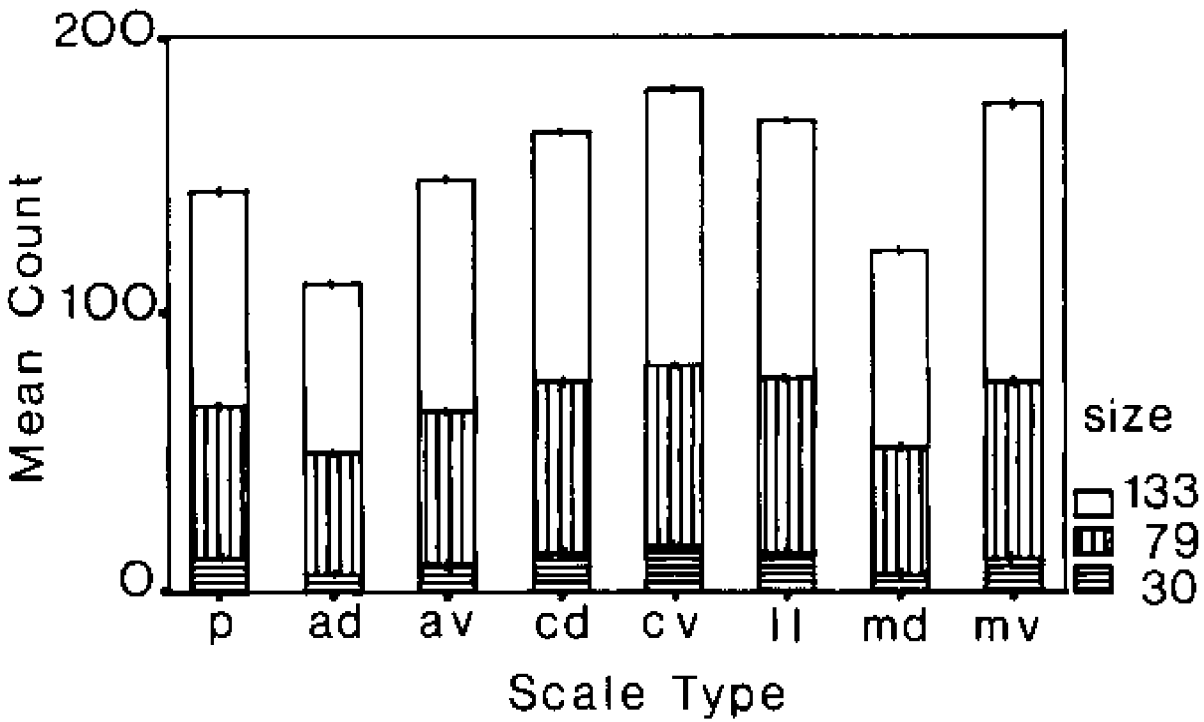

200
100
0
Mean Count
p
ad
av
cd
cv
ll
md
mv
Scale Type
size
133
79
30

Figure 11. Standard length on scale circuli count regression for weakfish, York River, VA. $Y=0.97X+14.2$, $r^2=0.96$, $n=922$.

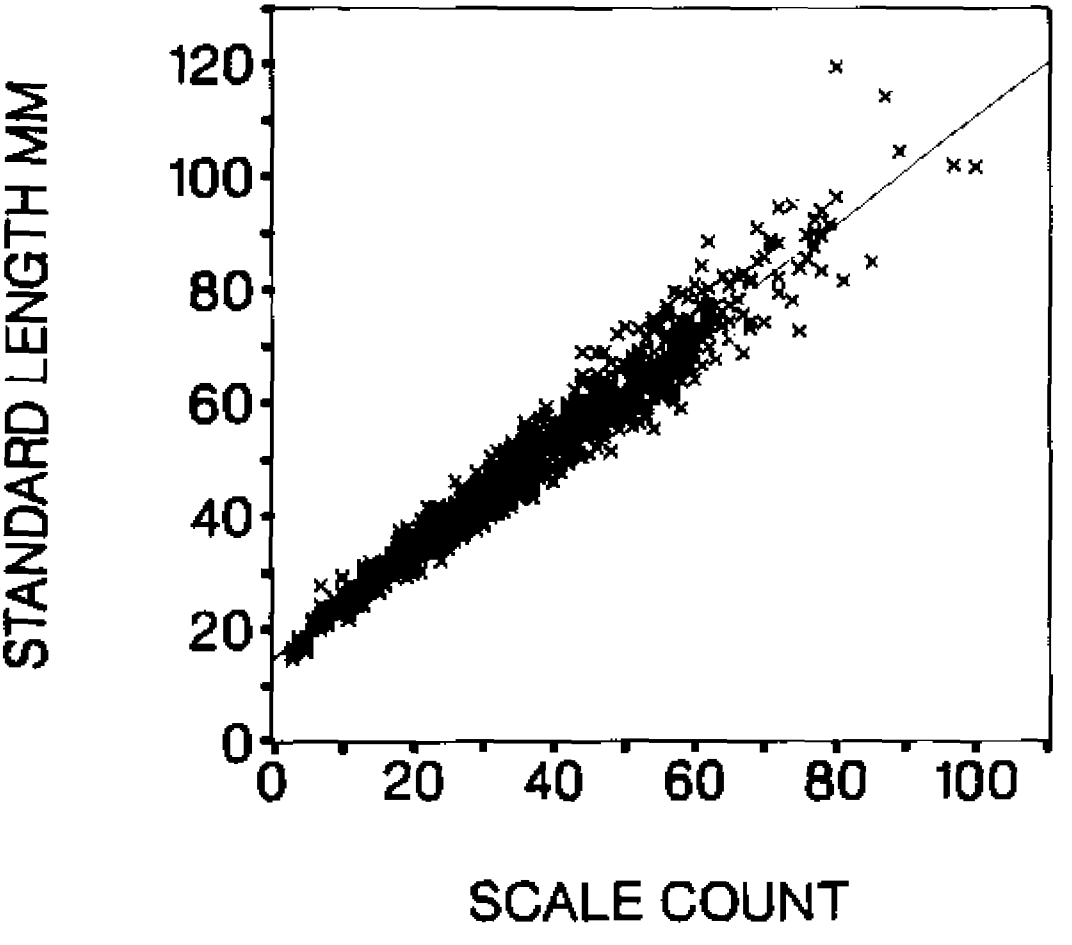

STANDARD LENGTH MM
120
100
80
60
40
20
0
0
20
40
60
80
100
SCALE COUNT

Figure 12. Quadratic regression of known age on standard length. $Y=0.016X^2+0.04X+2.3$, $r^2=0.69$, $n=548$.

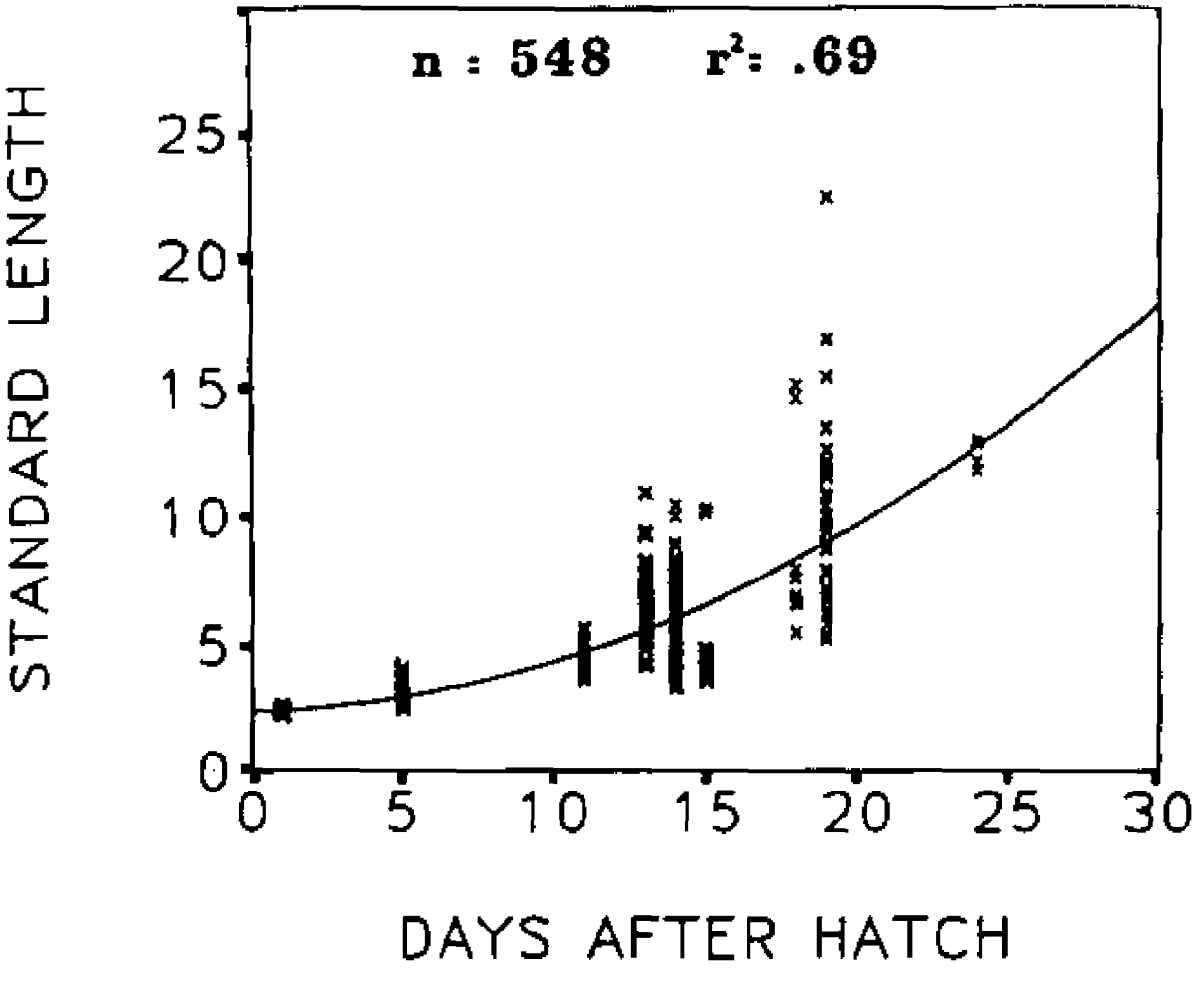

n = 548 r²= .69
STANDARD LENGTH
0
5
10
15
20
25
0
5
10
15
20
25
30
DAYS AFTER HATCH

Figure 13. Quadratic regression ($Y=-0.002X^2+1.14X-24.4$; $r^2=0.94$; n=40) of a single known age juvenile weakfish on scale circuli count. Straight line is for comparison, b=1.0.

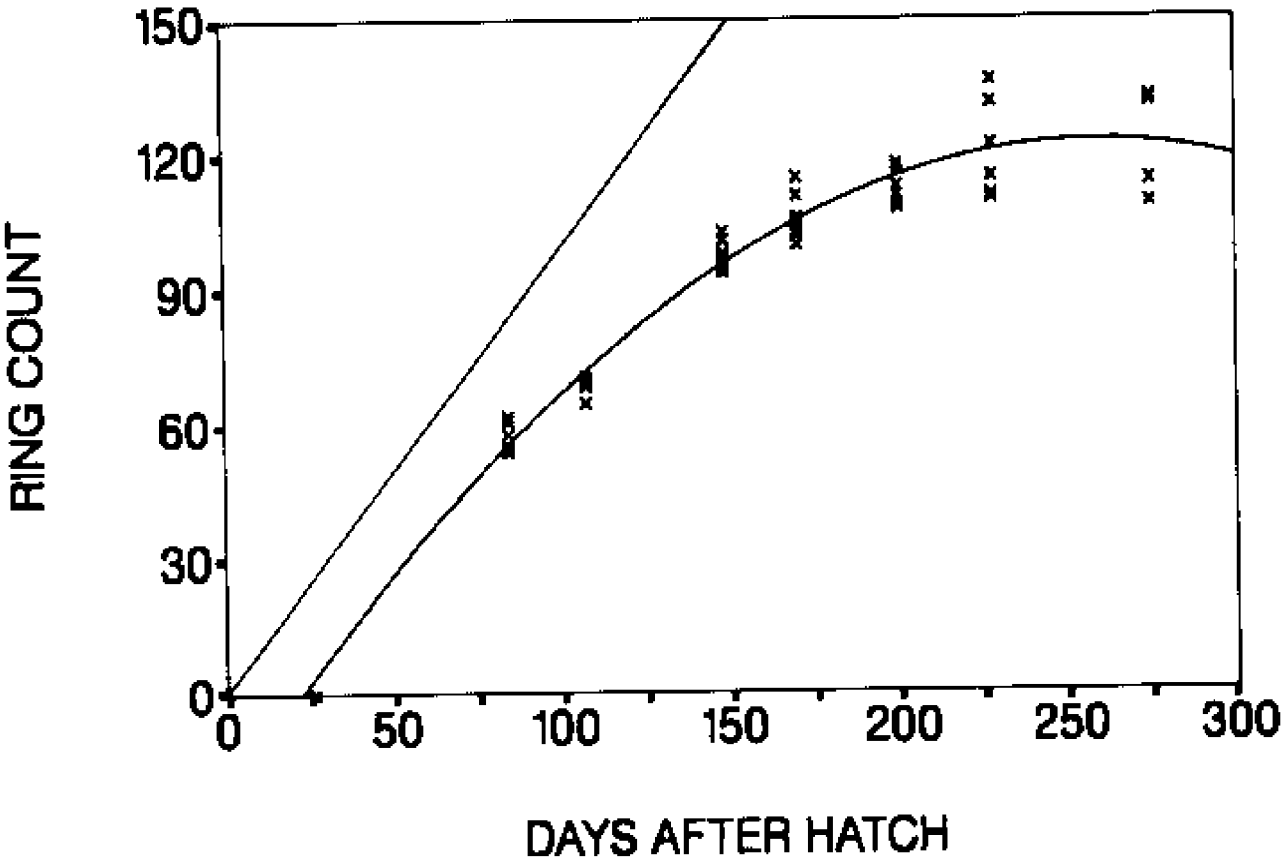

150
120
90
60
30
0
RING COUNT
0
50
100
150
200
250
300
DAYS AFTER HATCH

Figure 14. Scale circuli count after tetracycline mark in eight older juvenile weakfish (>80 mm SL) on days after mark ($Y=-0.01X^2+0.529X-1.5$; $r^2=0.87$; $n=205$).

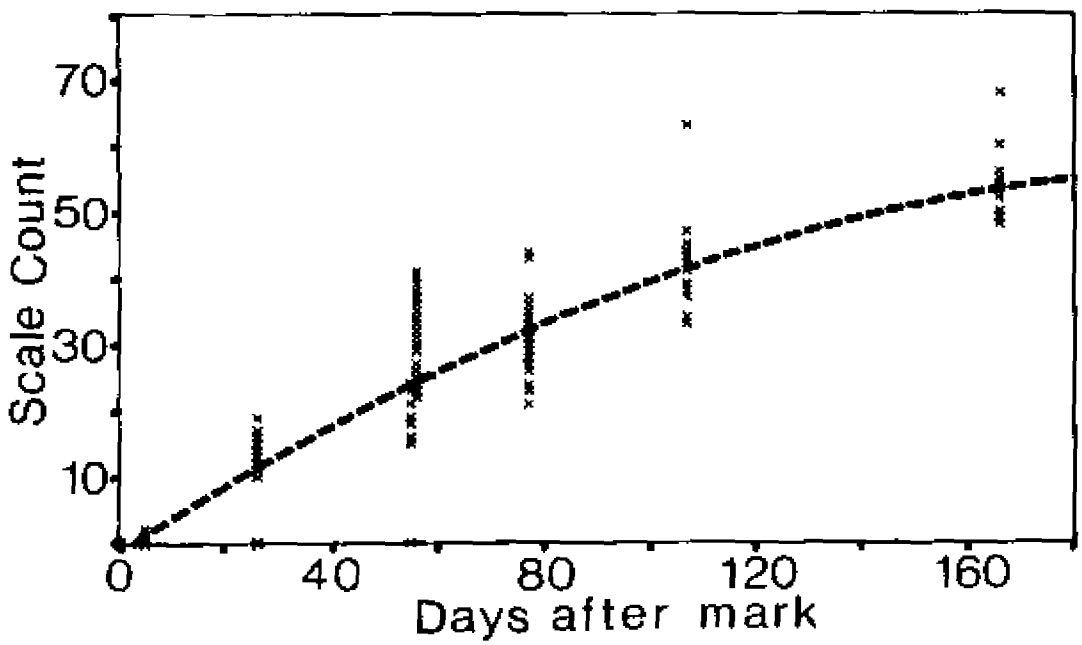
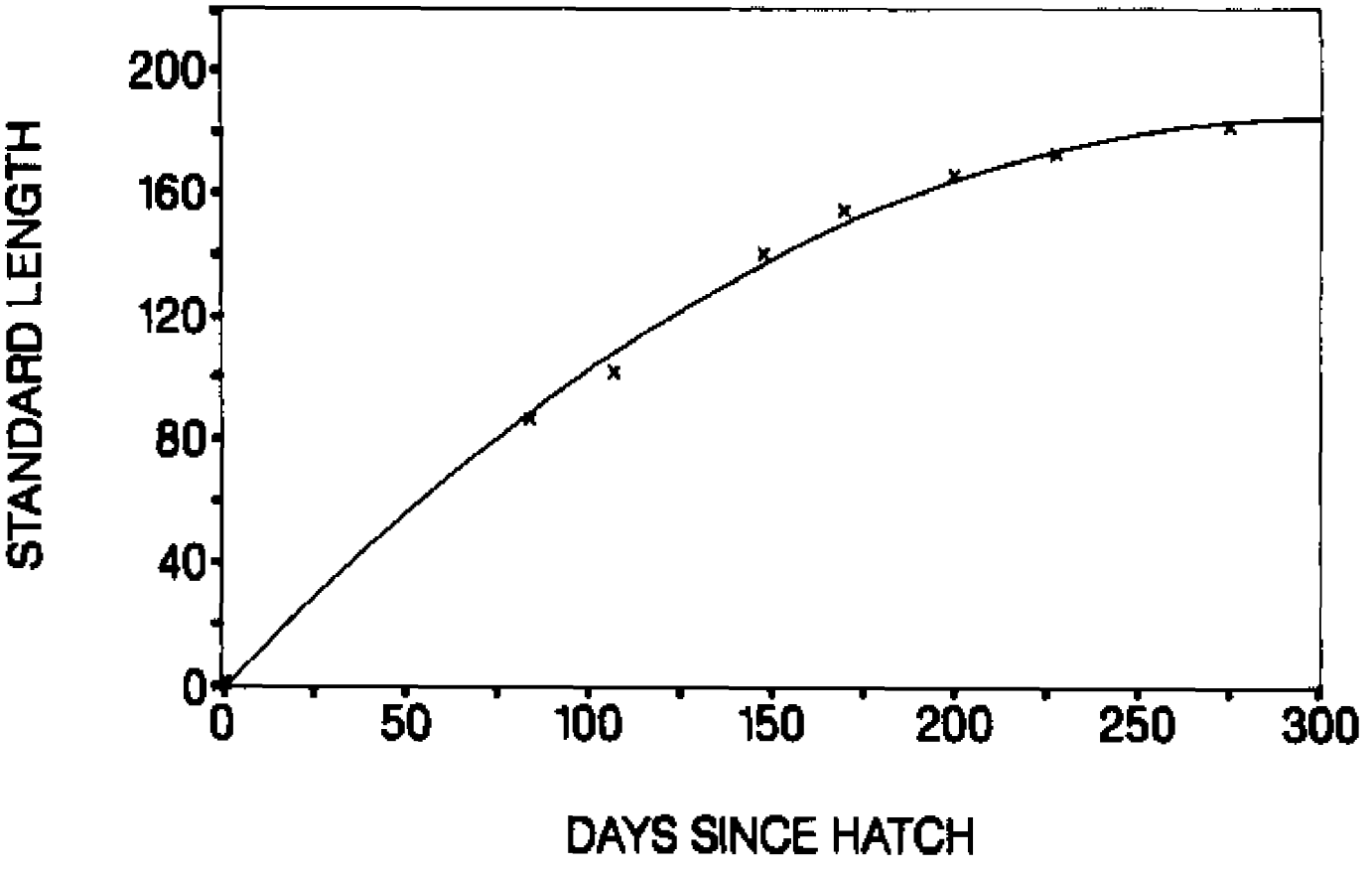

70
50
30
10
Scale Count
0
40
80
120
160
Days after mark

Figure 15. Quadratic regression of known age of a single reared fish versus standard length up to 275 days ($Y=-0.002X^2+1.24X-1.2$; $r^2=0.997$).


STANDARD LENGTH
200
160
120
80
40
0
0
50
100
150
200
250
300
DAYS SINCE HATCH

CHAPTER 3

AGE AND GROWTH OF JUVENILE WEAKFISH IN THE YORK RIVER, VIRGINIA

INTRODUCTION

An implicit assumption of early life history studies has been that the most critical period occurs during the egg and larval stages, after which juvenile abundance can be correlated with the following year class strength (Hjort 1914; May 1974; Victor 1986). This assumed steady state i.e., constant mortality of juveniles after the larval period (Williams 1983; Sale and Douglas 1981; Hewitt et al. 1985), has caused researchers to focus on egg and larval stages (Moser et al. 1984). However, prediction of year class strength through juvenile abundance has been questioned (Walline 1985; Eckert 1987; West and Larkin 1987); these authors suggested that survival of juvenile fishes after metamorphosis from larval stages is highly variable, i.e., critical "bottlenecks" are still encountered. The existence of multiple cohorts within 0-age juvenile fishes may help explain some of the variation (Buchanan-Wollaston and Hodgson 1929; Cooper 1937) but until recently it has received little attention (Lambert and Ware 1984). Several Cynoscion spp., show protracted spawning and bimodal size frequency distribution of juveniles (Harmic 1958; Massmann 1963; Merriner 1976; Shlossman and Chittenden 1981; DeVries and Chittenden 1982). This a priori knowledge suggest that weakfish may also have a highly variable juvenile stage, and study of that period will help in predicting year class strength.

Juvenile weakfish populations can best be examined through growth rate, because growth integrates the variability in food and other

environmental conditions (Werner and Gilliam 1984; Weatherley and Gill 1987). The key to evaluating growth rates is the ability to age young fish. Until recently (see reviews: Campana and Neilson 1985; Jones 1986) the only method for aging larval and juvenile fishes was through length frequency analysis, a cumbersome method (Graham and Townsend 1985). Pannella (1971) showed that daily aging could be accomplished by counting microscopic banding in fish otoliths. This method was unsuccessful for weakfish, but a new method of daily aging by counting circuli in scales was developed in this study.

The present study uses this new method of daily aging through scale circuli counting with standard length measurements to estimate growth rates of juvenile weakfish. Birthdate frequency distributions are estimated from weakfish age at time of capture, and the existence of separate cohorts within 0-age groups are shown. In addition, age frequency distributions are used to suggest migration patterns in the York River estuary, Virginia.

MATERIALS AND METHODS

The York River and its major tributaries represent an estuarine system which is relatively well known biologically and mostly undisturbed (Boesch, 1971). General trends of geomorphology, hydrography, ecology, and alteration by man were described by McHugh (1967) and Boesch (1971). In addition, the general biology of sciaenid fishes is well known in the York River (Chao and Musick 1977; Weinstein et al. 1984; Norcross and Austin 1988).

Stations in the York River channel were sampled by night trawling (Leber and Greening 1986) with a 4.9 m (1.5 mm cod end) trawl, and included four locations: 0, 15, 33, and 45 km upriver (Fig. 16). Sampling started 13 August, and proceeded weekly until 26 October, 1983. Repetitive 2 min trawls were made at each station until 30 fish were captured or until 6 tows were completed (in some cases number of trawls were fewer due to weather conditions). Salinity and temperature were recorded for all stations at surface, mid, and bottom depths, with a Beckman conductivity meter, and subsequently averaged by depth.

Weakfish were stored in 70% ethanol, and preservative changed to fresh ethanol in 24 hr. Standard lengths of preserved fish were recorded with Mitutoyo calipers to the nearest 0.1 mm. At least three scales (usually five) were removed from just below the mid body lateral line curve and embedded on a glass slide with methacrylate (Chapter 2).

When three scales could not be taken, the fish was not used. Scale circuli were counted as described in Chapter 2.

The highest increment count from separate scales was used in all subsequent analysis. Age of York River fish were estimated from a known age on scale count quadratic regression (Fig. 13). Birthdate frequency distributions were generated for all fish aged. All birthdate frequency distributions were smoothed with a 3-day moving average. After identifying cohorts within the yearclass (Graham et al. 1984), fish were arbitrarily divided into their cohorts by separation at minimum frequency dates and growth rates determined. Mortality rates were determined by decline in mean catch over time for each cohort (Essig and Cole 1986).

Migration patterns were suggested by examination of age frequency distribution over station and date. On one occasion scale samples were lost (station 1, 23 August), and age distribution was calculated from a known age on standard length quadratic regression (Fig. 15). Habitat utilization by cohorts was examined through birthday frequency distribution over station and date, and occurrence of cohorts were considered common when mean catch modes were greater than 0.5 fish mean catch/ 2 min trawl.

A 0.05 level of significance was used for all statistical analysis. Nonparametric two-way analysis of variance by ranks was used to test for abundance differences. Analysis of covariance was used to test for significant differences in growth rates for 3 or more comparisons among cohorts, stations, and cohort-station interactions. A t-test was used for comparison between two slopes (growth or mortality rates). After

significance was determined, Tukey's test for comparison among slopes was used to show specific differences (Zar 1984; Freund et al. 1986).

RESULTS

Salinity decreased as distance up the York River increased. One exception occurred in late September, a reverse salinity gradient was observed between stations 2 and 3 (Fig. 17). Little difference was detected in temperature among stations. Seasonally, temperature decreased from 29°C in July to 16°C in October.

Nonparametric analysis of variance of standardized abundance failed to show any statistically significant patterns (Appendix 1, 2). However, certain trends in abundance are worth mentioning. In early August fish were uncommon at all stations, and first became abundant at the York River mouth in mid-August, subsequently this abundance mode moved upriver with later sample dates (Fig. 18). In late September through mid-October, weakfish were most abundant at intermediate stations 2 and 3, and by late October few fish were collected at any station.

Scale counts ranged from 3 to 100, for all fish aged (845 aged/992 collected). The birthdate frequency distribution for aged fish, showed three cohorts within the 1983 yearclass, and possibly a fourth spawned early in the season (Fig. 19; Appendix 3). Cohorts were defined as follows: cohort 1 fish were hatched before 16 July, cohort 2 between 16 July and 15 August, and cohort 3 fish after 15 August. A fourth cohort may have been present before 18 June, but its identification is

tentative therefore, these fish were pooled with cohort 1. Analysis of covariance of growth rates separated by cohorts and stations showed significant differences among cohorts and among stations, but third order interactions were not detected (Fig. 20; Appendix 4). Tukey's test for comparison among slopes (growth rates) among stations showed that station 1 fish, had a significantly faster growth rate (Fig. 21); and in comparisons of different cohorts, cohort 1 fish, had a significantly slower growth rate (Fig. 22). In addition, mortality rates were significantly lower for cohort 1 compared to cohort 2 (Fig's. 23, 24: Appendix 5).

Separate cohorts within a year class were also identified by standard length frequency analysis (Fig. 25). Pooled by stations, 3 cohorts were persistent through time (criteria: greater than 12 mm separation of mode; identified for more than 3 sampling dates) to enable growth rate estimates through modal size progression. A fourth cohort that corresponds to the early cohort in figure 19 did not meet the above criteria.) No significant differences in growth rate (analysis of covariance) were detected among cohorts (Fig. 26).

Weakfish of 0-age, first recruited to the York River nursery at station 1, from 17-August to 9-September (Fig. 27). Approximately the same age distributions occurred over four collection dates at station 1, after which fish were uncommon, suggesting that fish quickly moved elsewhere (Fig. 27). Figures 28-30, indicate that fish moved upriver as they grew, i.e., over the same sample dates mentioned above, age distributions showed progressively older fish as samples were taken further upriver. This pattern continued for sample dates 17 - 20 September, however, all fish were older than previous collections at the

same stations, indicating recruitment to the York River nursery had slowed. On 26 September, the age distribution at station 2 suggested some new recruits were present that were not observed passing through station 1, but the pattern of older fish upriver still held. Collections from 4 October, showed the oldest group of fish for the season that were relatively common located at station 3, but also showed the appearance of older fish for the first time at station 1, indicating a down river migration.

Birthdate distribution over time and station suggested three patterns of weakfish cohort utilization of the York River nursery (Figs. 31-34): First, fish were common at 3 consecutive stations and rare at the fourth station (either upriver at station 4 or at the river mouth station 1) dependent on sampling date; Second, cohort 1 appears to utilize upriver nursery waters more than cohorts 2 or 3; Third, both cohorts seem to follow an upriver migration through September, followed by a downriver migration through October. Table 2, was generated from figures 31-34, and shows the three patterns mentioned above.

DISCUSSION

To my knowledge this is the first direct age measurement of individual field collected juvenile weakfish, and has lead to new findings: identification of cohorts within 0-age groups that show significantly different growth and mortality rates. Chao and Musick (1977) studied juvenile weakfish in the York River but did not find bimodal size frequency distributions. An explanation of this discrepancy is not found in age frequency versus length frequency methods, because the latter also delineated cohorts in the present study. Chao and Musick (1977) did however use a trawl with a larger cod end mesh size (0.64 cm); pooled trawl data with a 15 m (0.64 cm) seine data; did not exclude 1-year old weakfish; and their length frequencies were pooled over ~3 mm size classes. Pooling size classes can be a problem as Buchanan-Wollaston and Hodgson (1929) have suggested, "a great deal of useful information can be lost by curve smoothing and combining data". Massmann (1963) suggested the existence of cohorts within 0-age groups of juvenile weakfish through bimodal size frequency distributions, but he did not examine growth rates or mortalities. Other than two early reports (Buchanan-Wollaston and Hodgson 1929; Cooper 1937) other juvenile fish species studies that identify cohorts are few and recent (Shlossman and Chittenden 1981; DeVries and Chittenden 1982; Crecco and Savoy 1985; Kumagai et al. 1985; Eckert 1987; Isely et al. 1987; Wicker and Johnson 1987). This lack may

be because of the difficulty of aging juvenile fishes (Geffen 1986; Essig and Cole 1986; Jenkins 1987; Post and Prankevicius 1987), or it has been assumed that the critical period occurs in the egg and larval stages, and subsequent juvenile growth and mortality rates were constant (Hjort 1914; May 1974; Victor 1986). This notion of constancy after nursery recruitment is being questioned (Walline 1985; Eckert 1987; West and Larkin 1987), for example: Wicker and Johnson (1987) show that critical mortality occurs in 0-age largemouth bass Micropterus salmoides, when juveniles shift from an invertebrate to fish diet, and van der Veer and Bergman (1987) suggest that predation by shrimp Crangon crangon, on newly settled juvenile plaice Pleuronectes platessa, may explain the difficulty of predicting year class through egg and larval surveys. However, field studies of American shad Alosa sapidissima, suggested that year class strength is established before the juvenile stage (Crecco et al. 1983; Crecco and Savoy 1984; Crecco and Savoy 1985). Therefore, the existence of critical periods during the juvenile stage appears species specific. Because different cohorts with variable growth and mortality rates are shown for juvenile weakfish in the present study, survival bottlenecks are probably important during this life stage.

Other differences between the present study and that of Chao and Musick (1976) are migration patterns and habitat utilization. In the present study the youngest weakfish were first abundant at the mouth of the York River, moved up river as they grew, and followed a reverse migration in the fall. Chao and Musick (1977) collected their smallest (youngest) weakfish upriver, because of the larger mesh size used, longer sampling period; and that length frequencies do not have the

resolving power found with age frequencies.

The demonstration that different juvenile weakfish cohorts use different habitats has also been suggested for the rudd Scardinius erythrophthalmus (Rheinberger et al. 1987). Cohort differential growth rates and habitat utilization of weakfish, may be linked to the salinity variation among stations, but many other factors not measured may also vary, for example: prey abundance, turbidity, currents, predation, to name a few, any of which may be linked to increased growth rates. In addition, the highly transitory nature of juvenile weakfish, as shown in the present study, makes it difficult to characterize the particular environment the fish occupied in the time before capture.

Although Chao and Musick (1977) did not estimate growth, I approximated it from their length frequencies, at 0.67 - 0.83 mm/d. These estimates are within the range of the present estimates, suggesting that juvenile weakfish from the York River in the earlier 70's were growing at present rates. Shenker and Olla (1986) provide estimates of juvenile growth rates for several species; with a low of 0.26 mm/d (Sebastes melanops), and a high of 4.7 mm/d (Coryphaena hippurus). Other growth rate estimates of juvenile fishes are similar: 1.5 mm/d for sablefish Anoplopoma fimbria (Boehlert and Yoklavich 1985); 1.0 - 1.3 mm/d for milkfish Chanos chanos (Kumagai et al. 1985); and 1.1 mm/d for American shad Alosa sapidissima (Crecco and Savoy 1985). Juvenile growth rates derived from length frequencies for other sciaenid fishes: C. arenarius (approx. 1 mm/d; Shlossman and Chittenden 1981), C. nothus (0.8-1.3 mm/d; DeVries and Chittenden 1982) and fish in the present study (1.0 - 1.2 mm/d) are similar to scale circuli calculated rates (0.8 - 1.1 mm/d). The above comparisons suggest that scale circuli aging in weakfish is a valid technique.

Hewitt et al. (1985) in their estimation of total mortality rate of jack mackerel Trachurus symmetricus, assumed a steady state, i.e., that each cohort experienced the same daily mortality rate, but also suggested that future studies test their assumption. Mortality rates from the present study are difficult to compare with other studies because the data do not appear to fit theoretical curvilinear rates of decline (Ricker 1975). The linear mortality curve that I observed, can not be correct because the population would go extinct quickly. Emigration from the York River system may have contributed to the linear "mortality" estimates (Chao and Musick 1977; Shepherd and Grimes 1983). Therefore mortality differences among cohorts may be migration differences or more likely a combination of mortality and migration.

The ecological advantage of cohorts can be thought of as a "hedged bet" strategy that spreads spawning effort over time to take advantage of a variable environment (Lambert and Ware 1984). However, distinct cohorts within 0-age fish can also result from environmental factors acting on a single spawning effort, for example: through diet and prey availability (Timmons et al. 1980; Keast and Eadie 1985; Wicker and Johnson 1987); or a combination of biotic and abiotic factors (Lambert 1984; Crecco and Savoy 1985). Assuming valid age determination the birth date distribution in the present study demonstrates that the main determinant of multiple cohort weakfish within 0-age groups is from multiple spawnings. Previous work on reproductive biology, eggs, and larvae are in agreement with the present conclusion that multiple cohorts result from multiple spawnings (Harmic 1958; Shepherd and Grimes 1984). Shepherd and Grimes (1984) showed that large weakfish "tiderunners" 55 to 80 cm entered the Delaware Bay estuary in the spring and spawned, subsequently in the summer these were replaced by 25 - 35

cm gravid weakfish with little overlap. Harmic (1958) showed a repeating pattern over three years, where weakfish eggs peaked in mid June, followed by a conspicuous gap, and another peak of eggs in mid July. Olney (1983) did not show a bimodal frequency for weakfish eggs and larvae in Chesapeake Bay. Olney's (1983) lack of multiple cohorts in Chesapeake Bay can be explained through sampling periodicity: He sampled once a month, and peaks and troughs of the present study and Harmic's (1958) are approximately 15 days apart.

In summary the present study clearly shows that separate cohorts exist within 0-age groups of York River weakfish. These cohorts show significant differences in growth and mortality/migration rates, consequently differential survival during this stage probably affects year class strength. Daily aging by scales, a new technique, is advantageous over standard length frequencies, particularly in estimating birthday distributions and subsequent delineation of cohorts. Albeit, as a new technique it is largely untested and future work should address the question of how independent are circuli counts from growth rate. If counts are independent of growth rate and a linear relation can be shown between scale radius and standard length, the same kind of survival studies that have been accomplished with otolith microincrements may be attempted (Methot 1983; Graham and Townsend 1985). There is some evidence such a relation may exist on a daily basis, for example: Healey (1982) and Sire (1986) suggest that distance between scale circuli decreased with growth rate in juveniles.

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TABLE 2. Specific habitat utilization by cohorts determined from birthday frequency distributions. C1=cohort 1, C2=cohort 2, C3=cohort 3.

Table 2. Specific habitat utilization by cohorts determined from birthday frequency distributions. C1=cohort 1, C2=cohort 2, C3=cohort 3.

	Dates								
Station	13Aug	17Aug	23Aug	30Aug	9Sep	17Sep	20Sep	26Sep	40ct	190ct	260ct
1									C1		
			C2	C2	C2				C2		
									C3		
2		C1	C1		C1	C1		C1			
				C2	C2	C2	C2	C2	C2		
								C3	C3	C3	
3		C1	C1	C1	C1	C1	C1	C1	C1	C1	
				C2		C2	C2	C2	C2		
										C3	
4						C1	C1				
						C2	C2				

Figure 16. Station locations for weakfish collections in the York River, Virginia: Station 1 (0 km, river mouth), station 2 (15 km upriver), station 3 (33 km upriver), station 4 (45 km upriver).

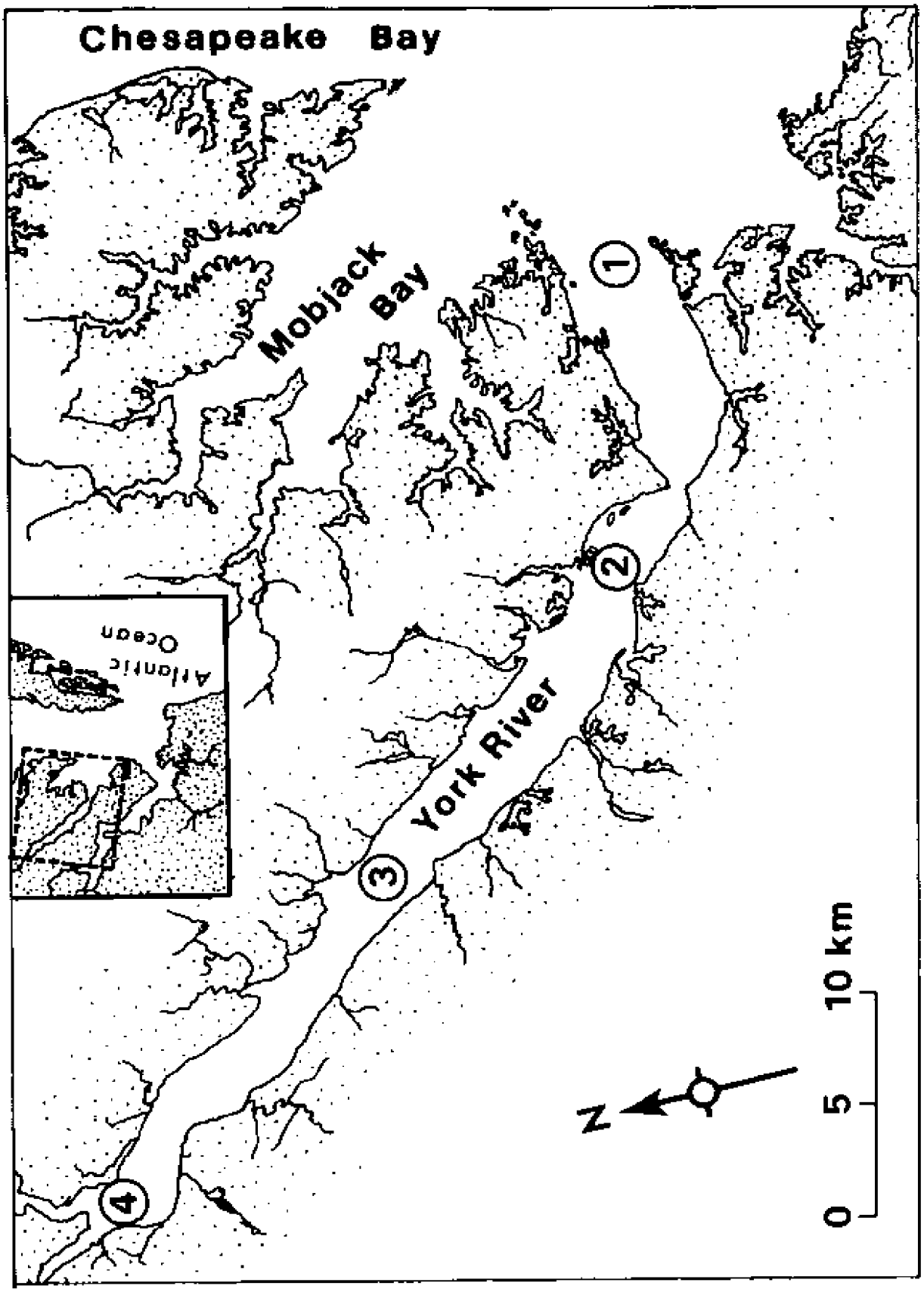

Chesapeake Bay
Mobjack Bay
York River
Atlantic Ocean
1
2
3
4
N
0
5
10 km

Figure 17. Salinity (ppt) and temperature (C) from all collections by station and date, pooled by depth.

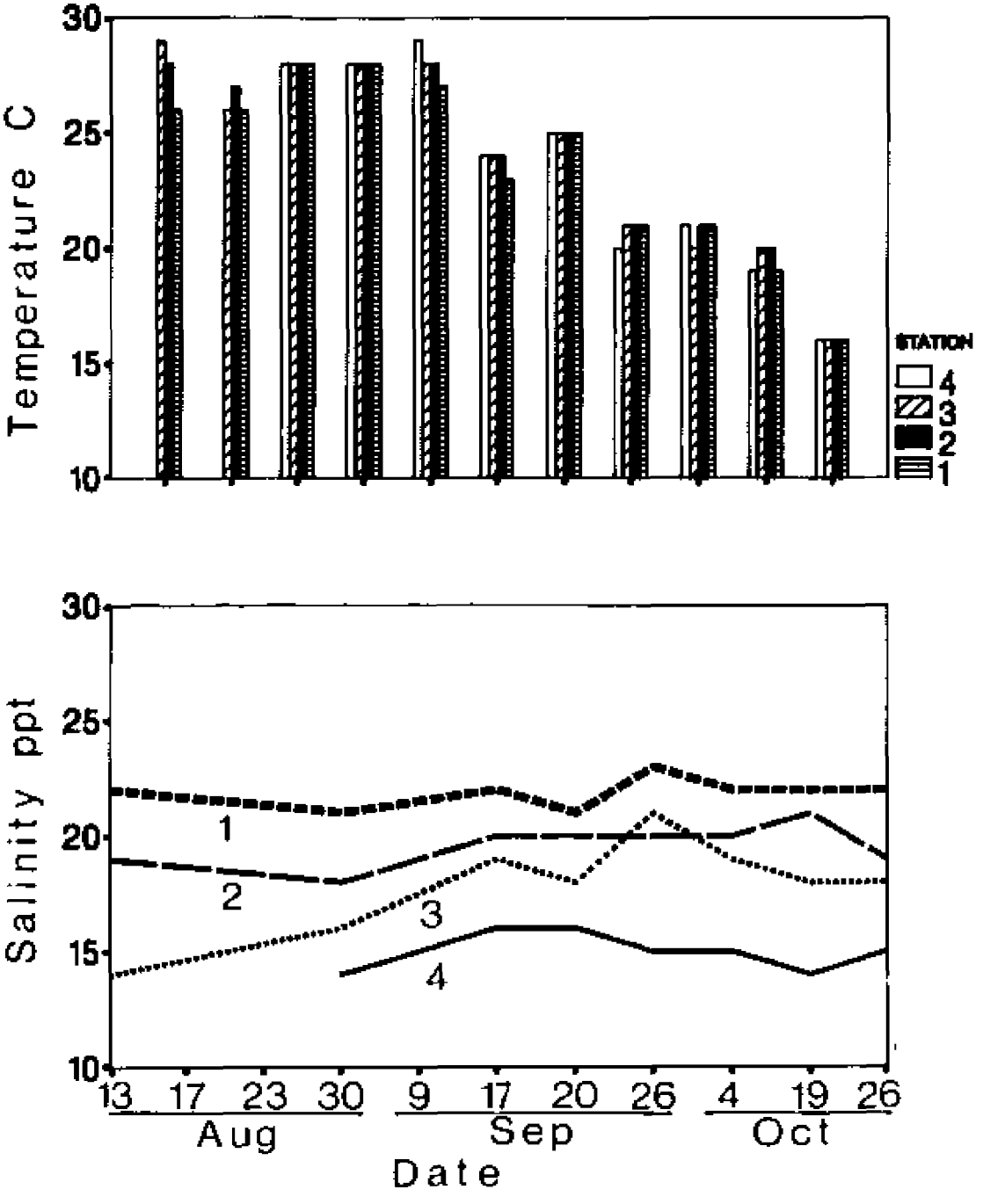

Temperature C
30
25
20
15
10
STATION
4
3
2
1
Salinity ppt
30
25
20
15
10
1
2
3
4
13 17 23 30 9 17 20 26 4 19 26
Aug
Sep
Oct
Date

Figure 18. Standardized abundance (Mean catch = #/2 min trawl) by station and date.

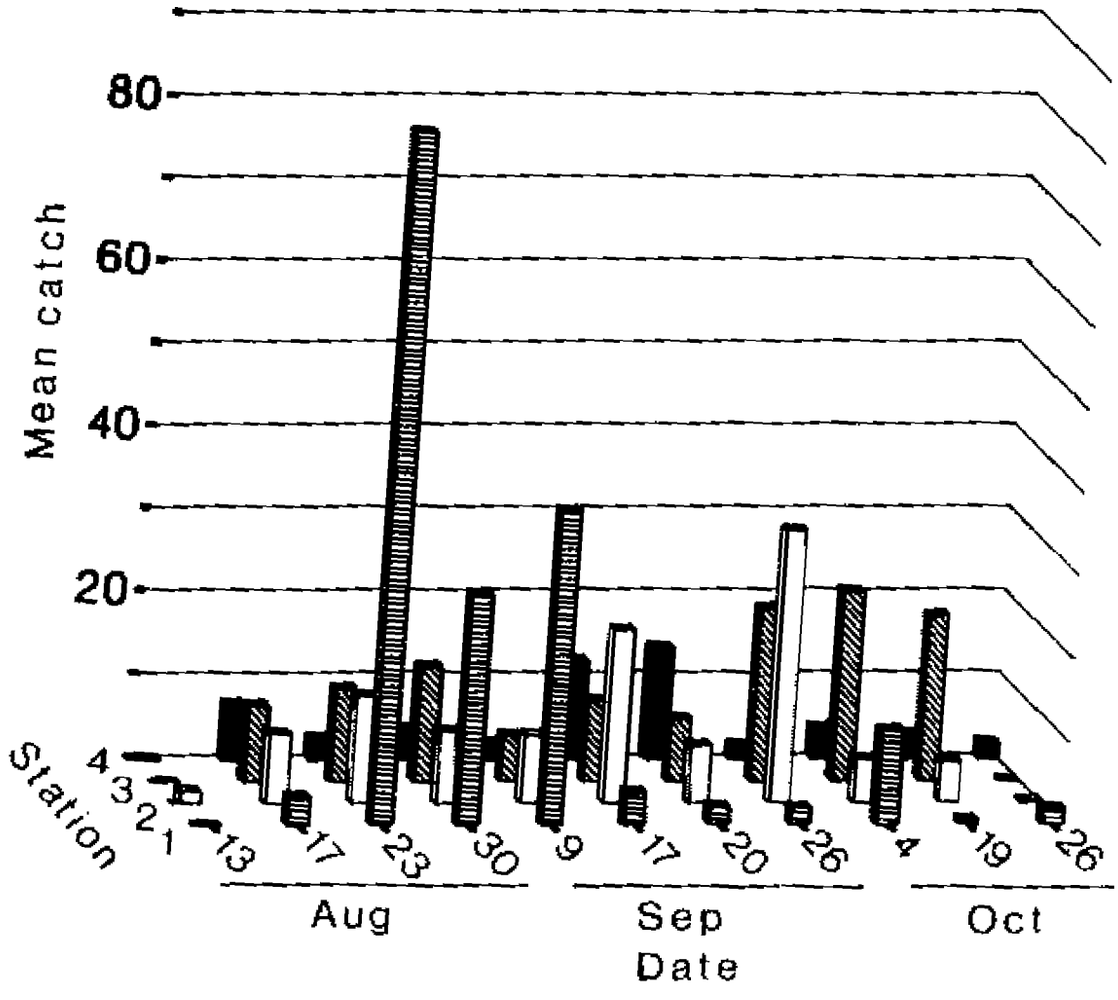

80
60
40
20
Mean catch
4
3
2
1
Station
13
17
23
30
9
17
20
26
4
19
26
Aug
Sep
Oct
Date

Figure 19. Birthdate frequency distribution, 3 point moving average, for 845 aged juvenile weakfish. The abscissa is divided into days, and number-letter indicates date of birth, starting with 21A=21-April and ending with 22A=22-August. Numbers at the peaks of the distributions refer to cohorts, which are separated by the dotted lines: 1=fish hatched between 18 June and 16 July; 2=those hatched between 16 July and 15 August; 3=those hatched after 15 August; ?=a tentative identification of an early cohort.

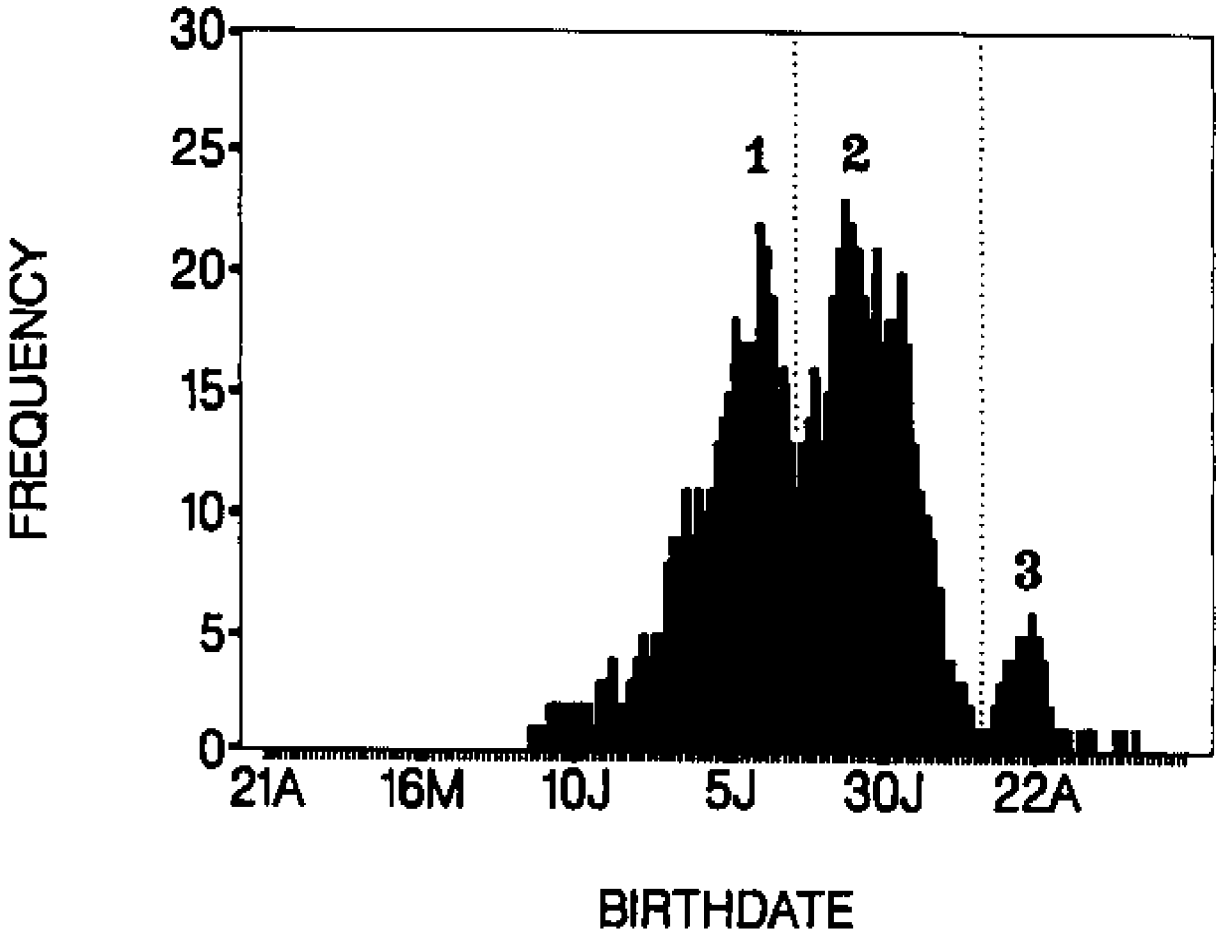

30
25
20
15
10
5
0
FREQUENCY
1
2
3
21A
16M
10J
5J
30J
22A
BIRTHDATE

Figure 20. Growth rates calculated from standard length on age, divided by cohorts and station. C1=cohort 1, S1=station 1.

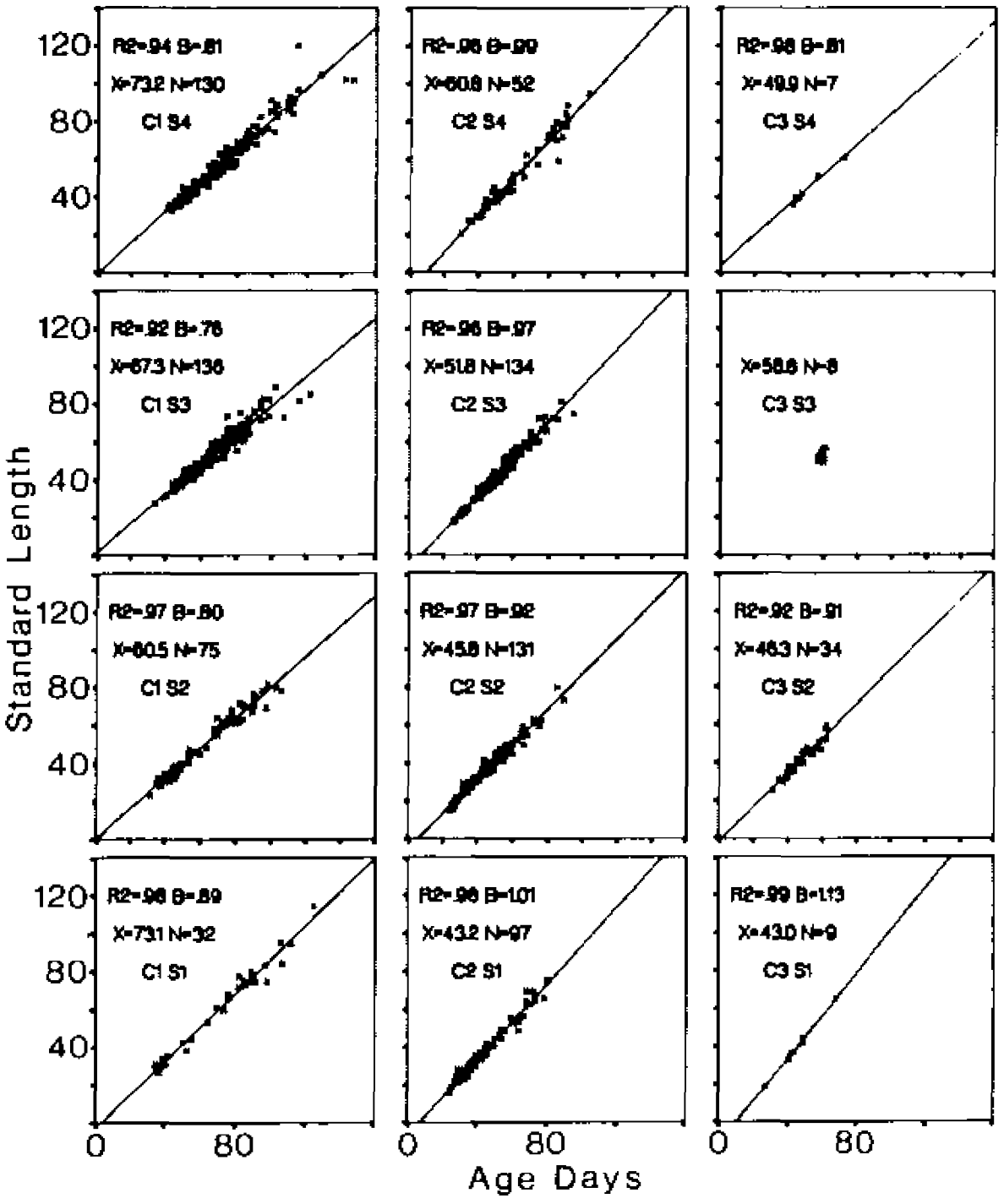

R2=.94 B=.81
X=73.2 N=130
C1 S4
R2=.96 B=.99
X=60.8 N=52
C2 S4
R2=.98 B=.81
X=49.9 N=7
C3 S4
R2=.92 B=.76
X=67.3 N=136
C1 S3
R2=.96 B=.97
X=51.8 N=134
C2 S3
X=58.6 N=6
C3 S3
R2=.97 B=.80
X=60.5 N=75
C1 S2
R2=.97 B=.92
X=45.8 N=131
C2 S2
R2=.92 B=.91
X=46.3 N=34
C3 S2
R2=.96 B=.89
X=73.1 N=32
C1 S1
R2=.96 B=1.01
X=43.2 N=97
C2 S1
R2=.99 B=1.13
X=43.0 N=9
C3 S1
120
80
40
0
80
Standard Length
Age Days

Figure 21. Growth rates for each station pooled by cohorts.

Station 4: Y=0.83X-1.22, n=189, r^2=0.94, x=68.9;

Station 3: Y=0.82X-0.46, n=278, r^2=0.93, x=59.6;

Station 2: Y=0.84X-1.62, n=240, r^2=0.96, x=50.5;

Station 1: Y=0.92X-4.41, n=138, r^2=0.98, x=50.1.

S1=station 1.

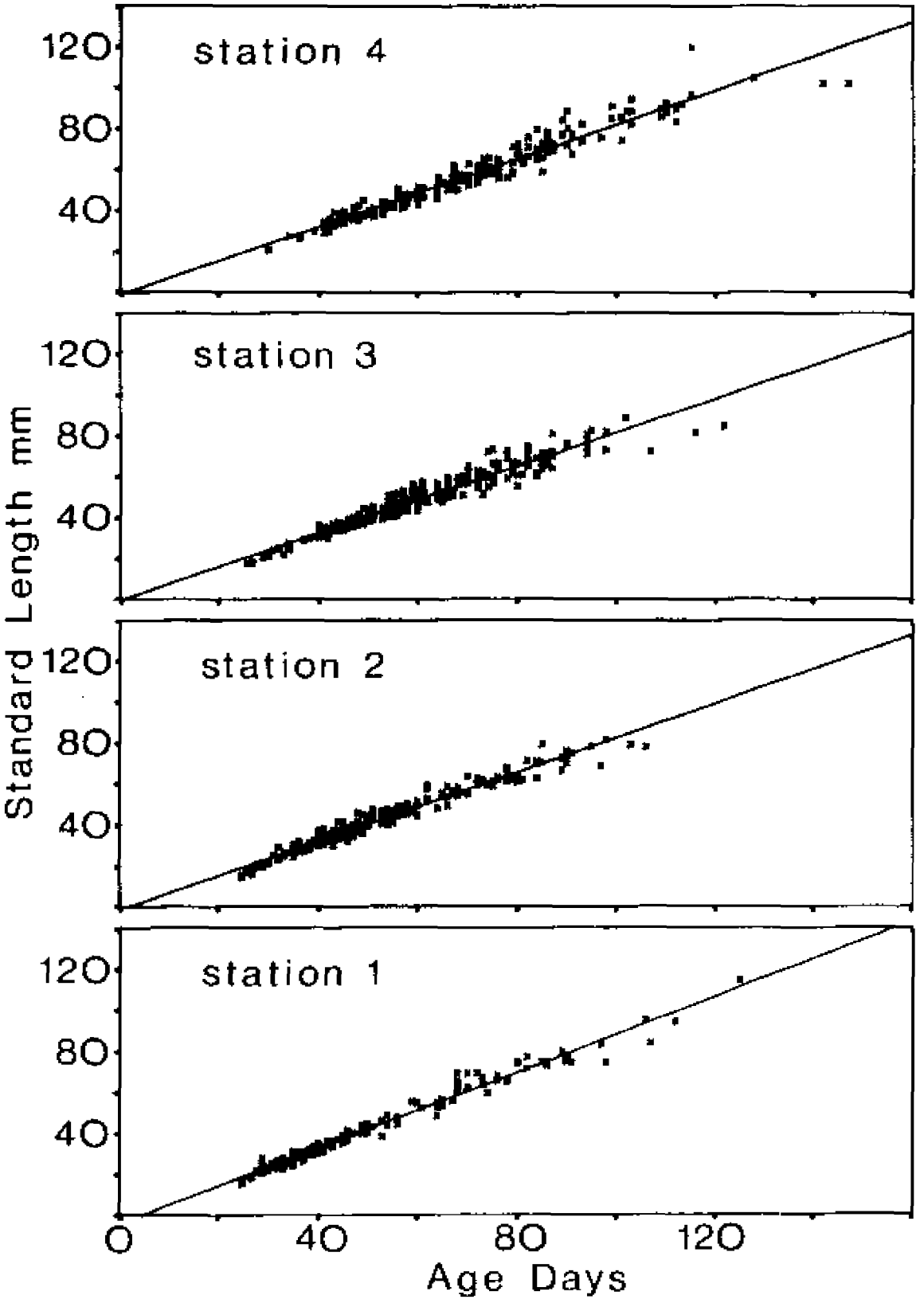

station 4
station 3
station 2
station 1
120
80
40
Standard Length mm
0
40
80
120
Age Days

Figure 22. Growth rates for each cohort pooled by station.

Cohort 1: $Y=0.82X-0.69$, $n=373$, $r^2=0.95$;

Cohort 2: $Y=0.96X-6.62$, $n=414$, $r^2=0.97$;

Cohort 3: $Y=0.97X-4.70$, $n=58$, $r^2=0.94$.

C1=cohort 1.

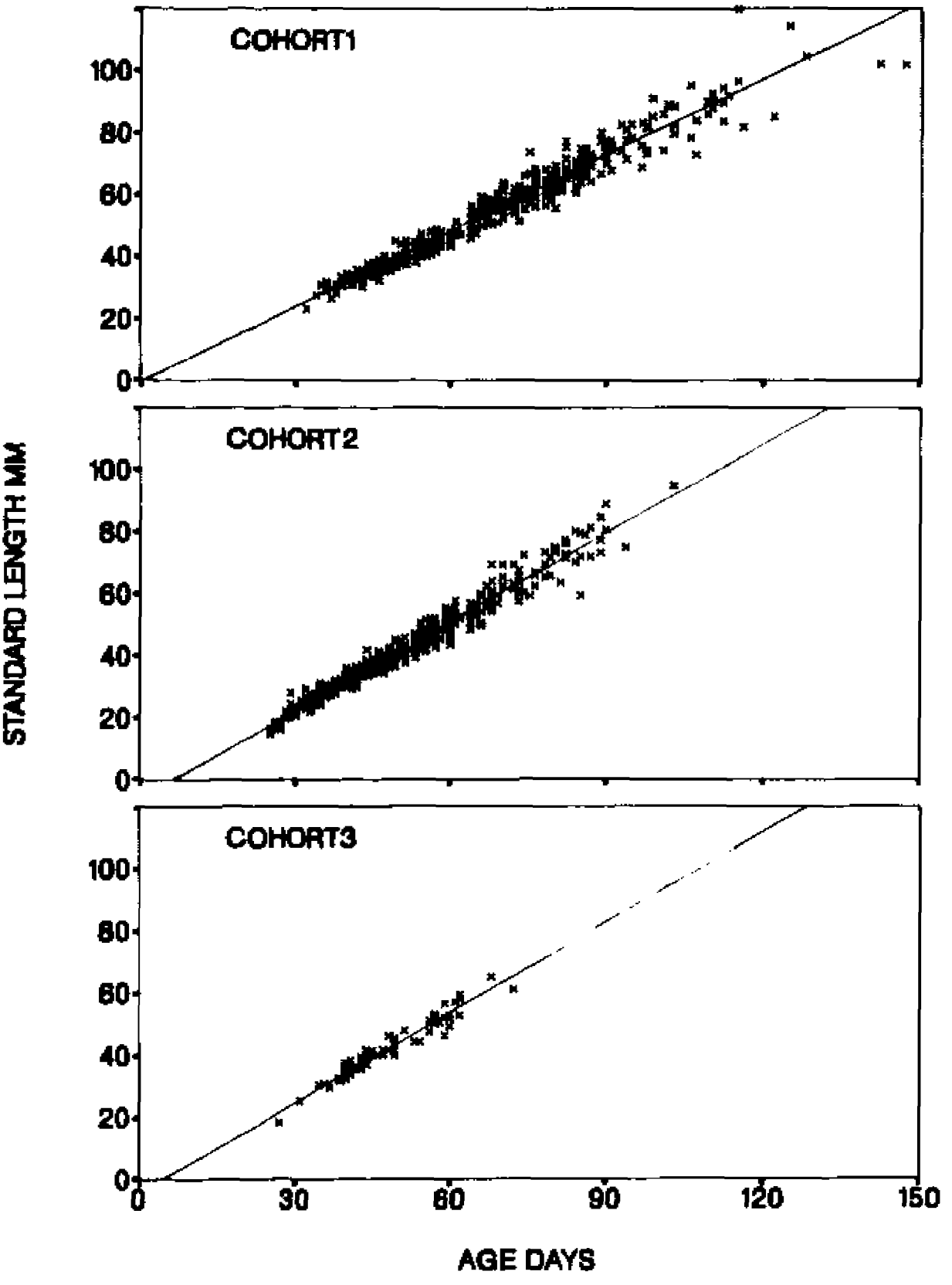

COHORT1
COHORT2
COHORT3
STANDARD LENGTH MM
AGE DAYS
0
20
40
60
80
100
0
30
60
90
120
150

Figure 23. Birthday frequency distribution 3 day moving average by date pooled over stations. The Abscissa is divided into days, and starts with 21A=21-April and ends with 8S=8-September. Dotted lines separate cohorts.

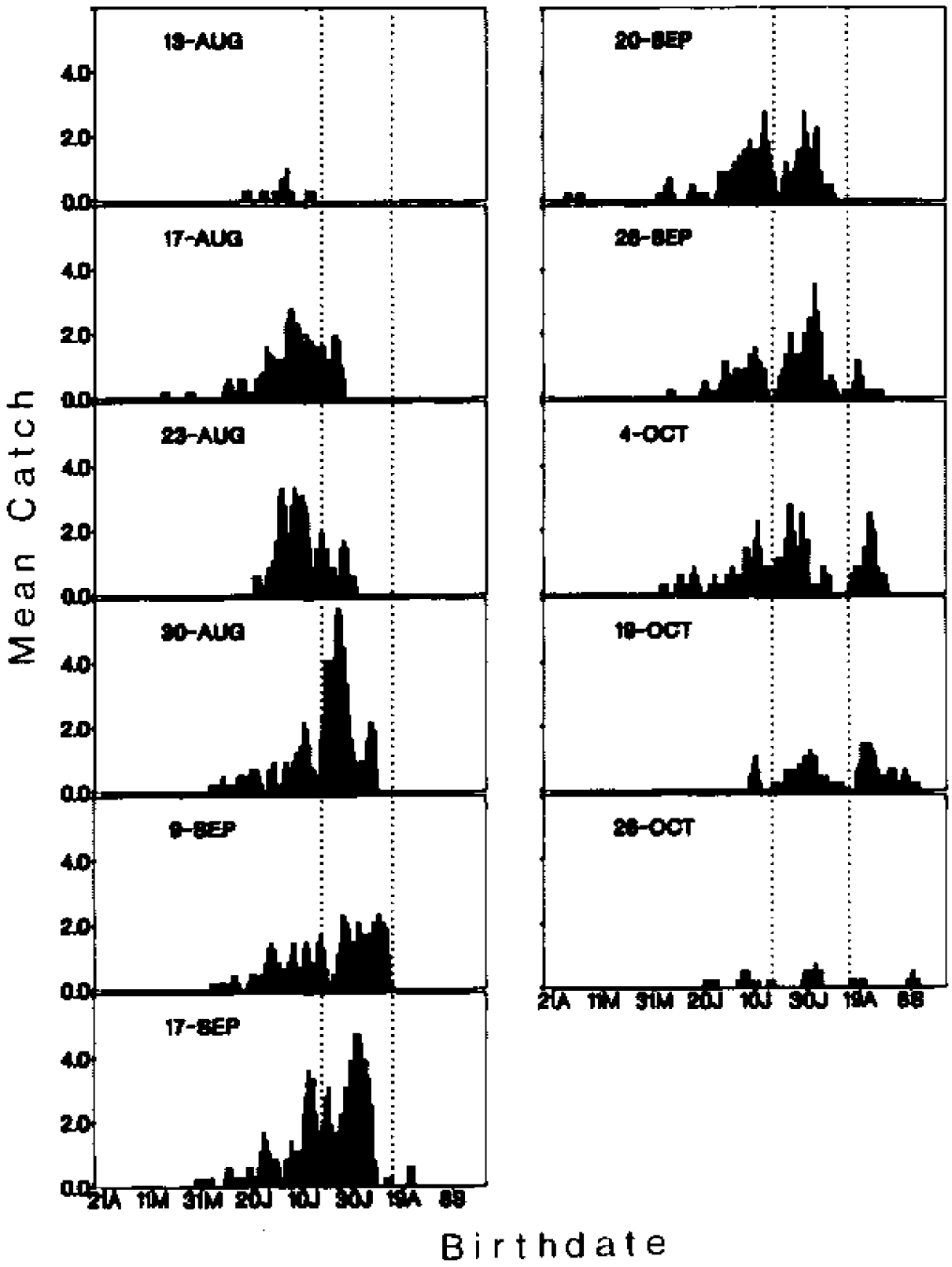

Mean Catch
19-AUG
17-AUG
23-AUG
30-AUG
9-SEP
17-SEP
20-SEP
26-SEP
4-OCT
10-OCT
26-OCT
4.0
2.0
0.0
21A 11M 31M 20J 10J 30J 19A 8S
Birthdate

Figure 24. Mean catch decline for each cohort after maximum frequency was reached, as determined from figure 23. Cohort 1: closed circles, $Y=-0.54X+44.5$, $r^2=0.83$; Cohort 2: open circles, $Y=-0.89X+70.4$, $r^2=0.92$; Cohort 3: X's was not present long enough for mortality rate calculation.

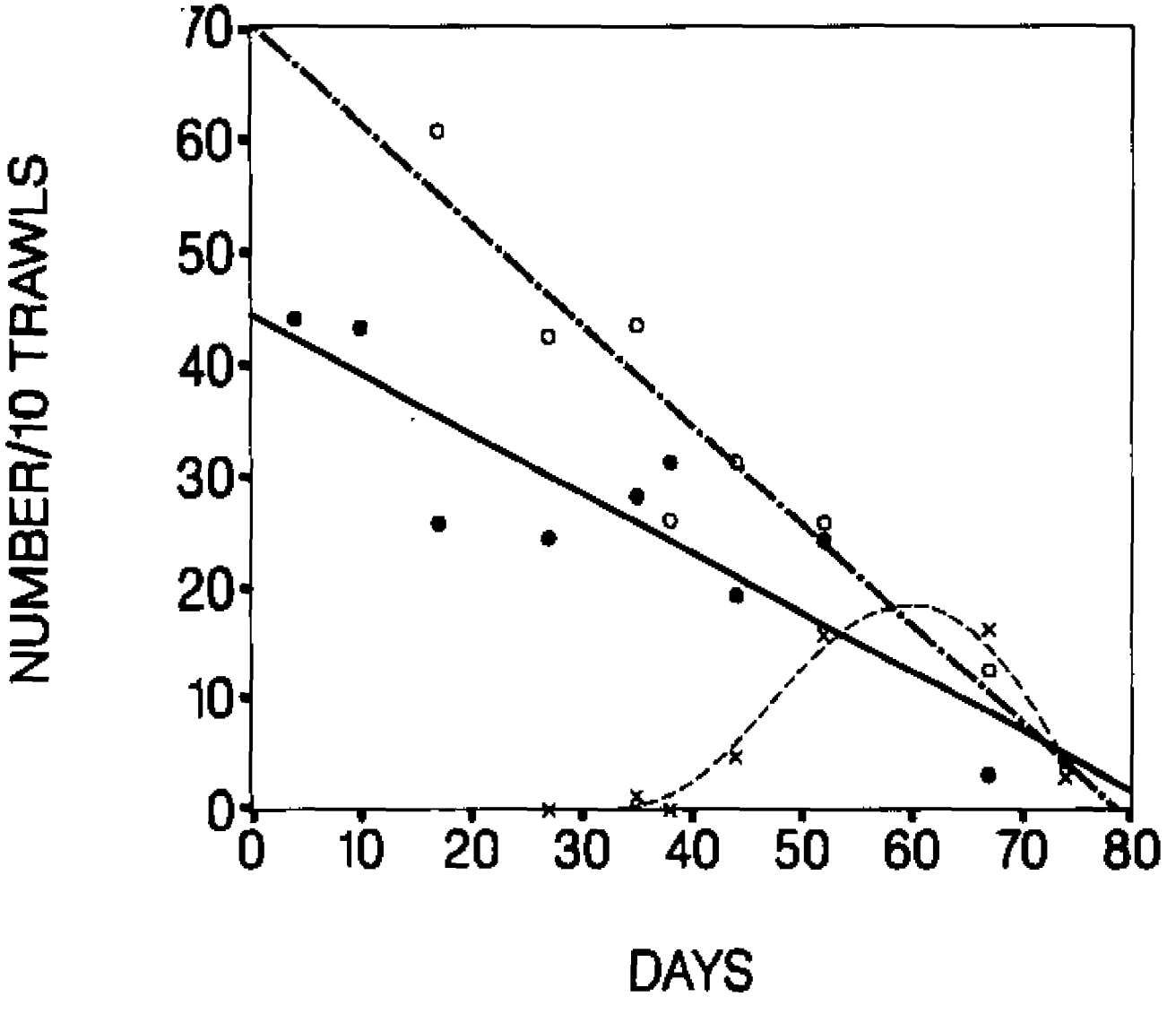

NUMBER/10 TRAWLS
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
DAYS

Figure 25. Standard length (mm) frequencies pooled by station for each sampling date. Cohorts are defined by, 1, 2, and 3. A (?) depicts a tentative forth cohort early in the season.

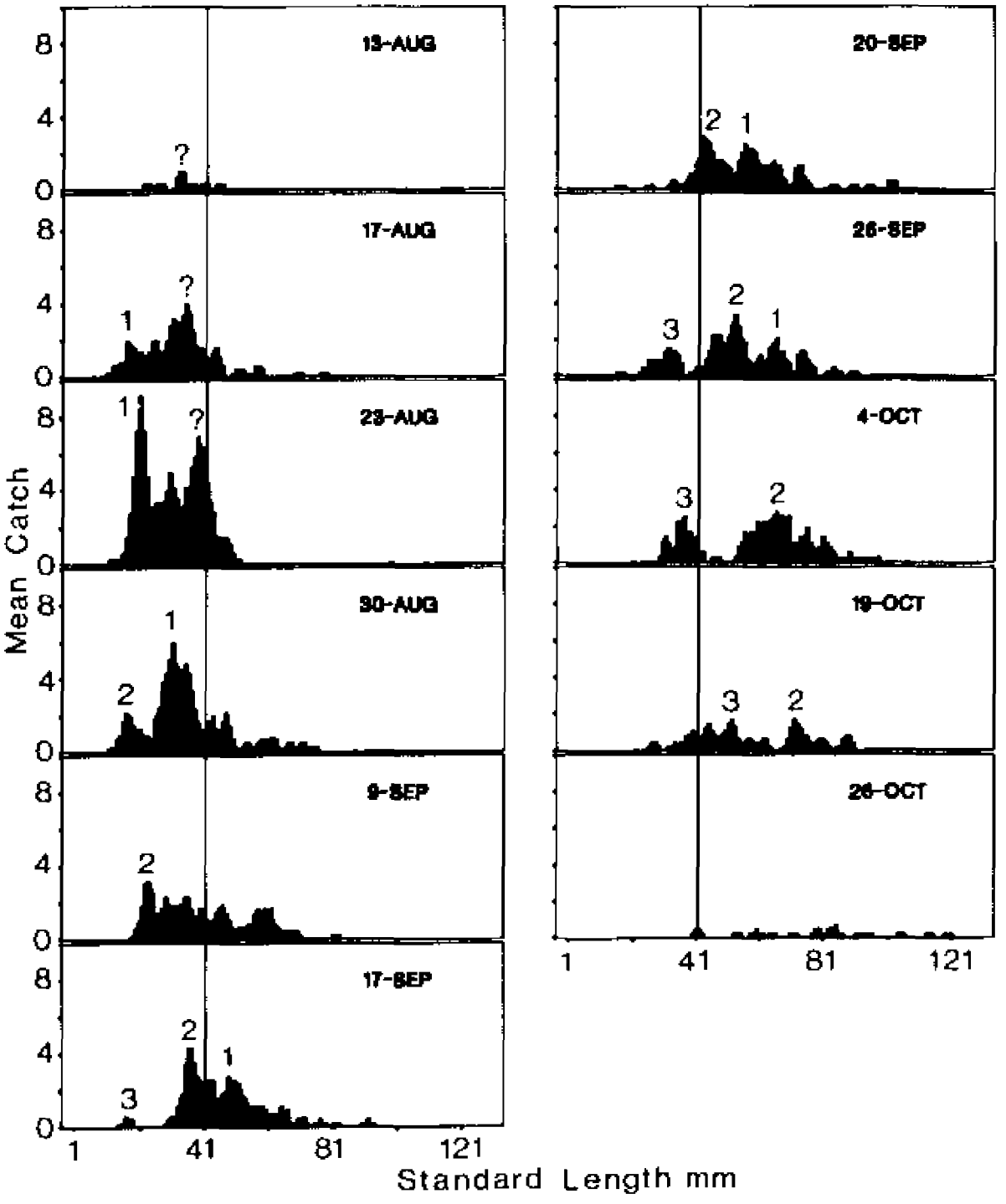

13-AUG
17-AUG
23-AUG
30-AUG
9-SEP
17-SEP
20-SEP
26-SEP
4-OCT
19-OCT
26-OCT
Mean Catch
Standard Length mm
0
4
8
1
41
81
121

Figure 26. Modal size on time between sample regressions from cohorts 1, 2, and 3, defined from length frequencies in figure 25. Open circles: cohort 1, $Y=1.2X+10.4$, $r^2=0.99$; closed circles: cohort 2, $Y=1.2X-4.3$, $r^2=0.96$; stars: cohort 3, $Y=1.1X-17.4$, $r^2=0.97$.

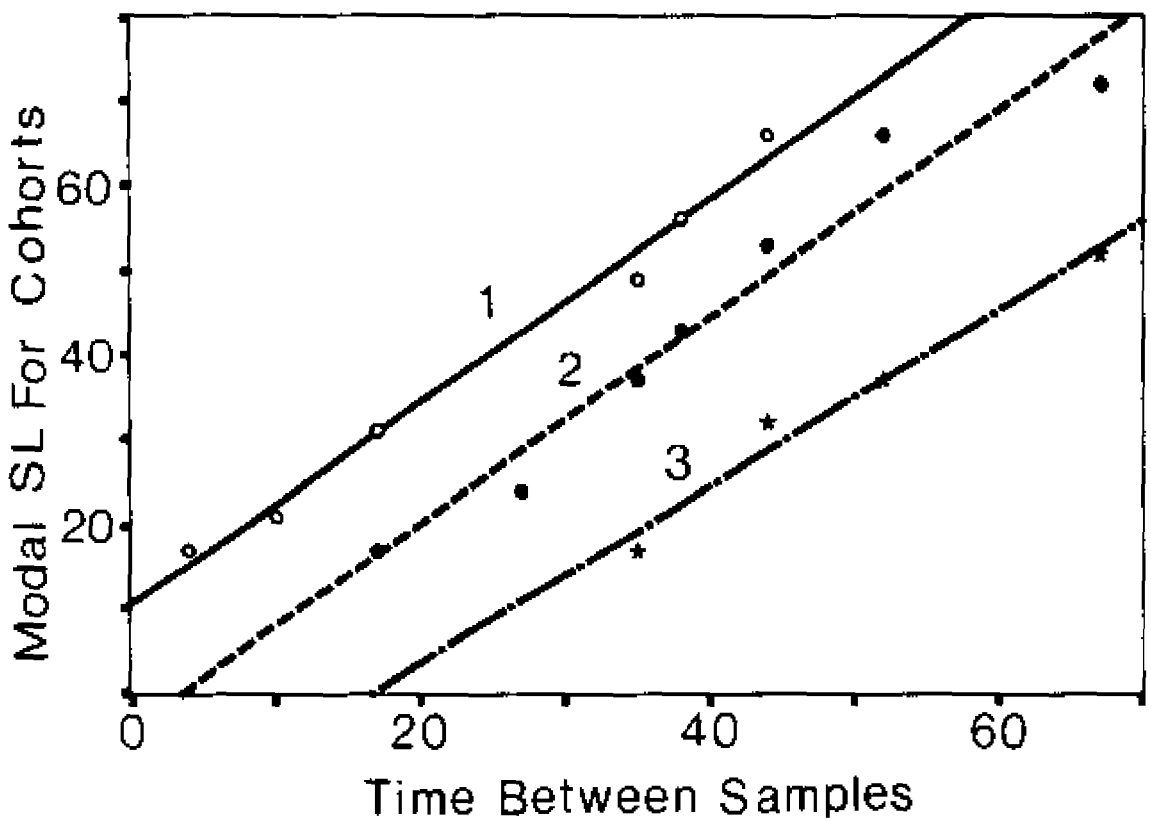

Modal SL For Cohorts
60
40
20
0
20
40
60
Time Between Samples
1
2
3

Figure 27. Age frequency calculated from counting scale circuli for station 1 (S1), by date of collection. Dotted line at 61 days is for comparison.

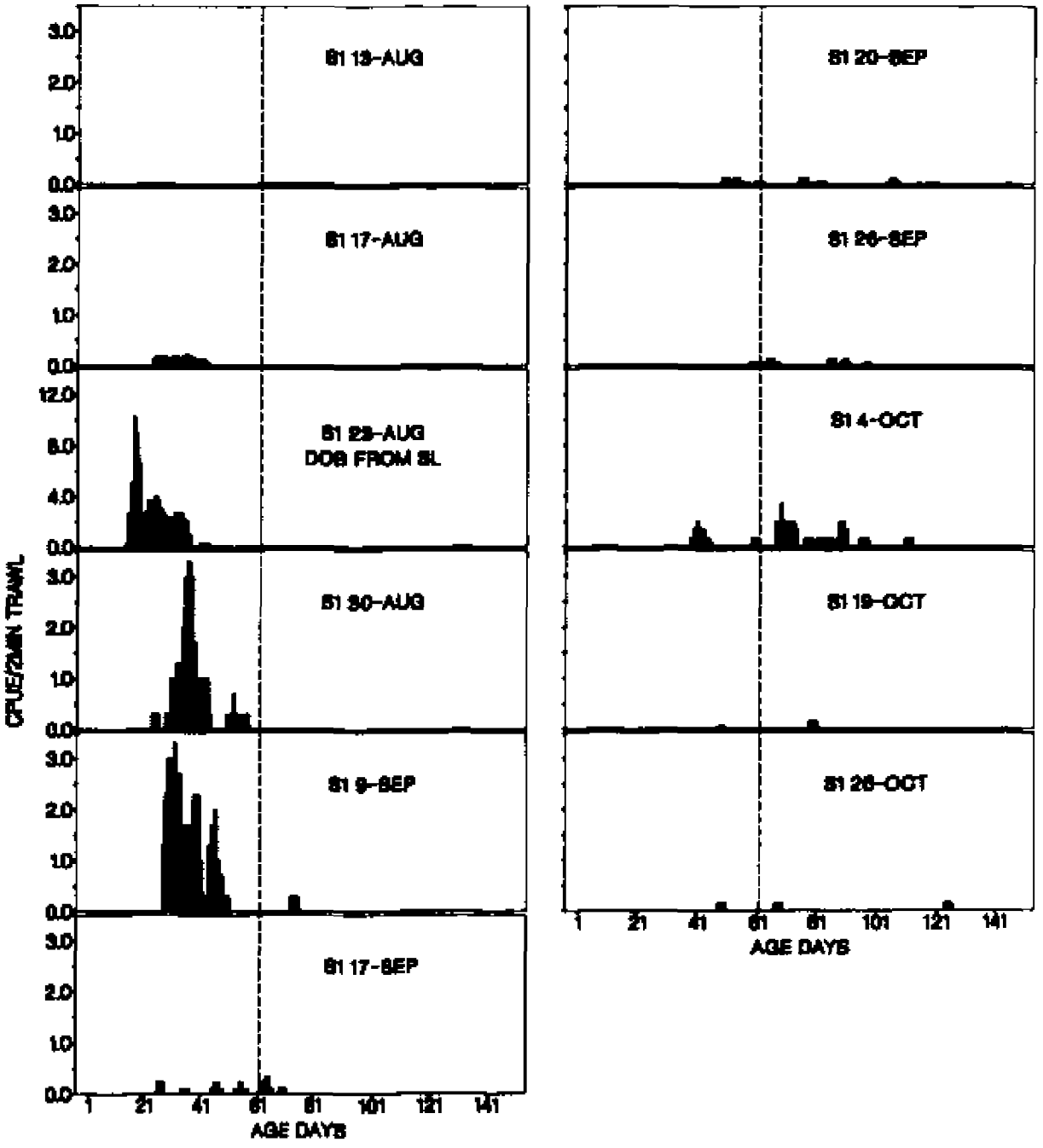

S1 13-AUG
S1 17-AUG
S1 23-AUG
DOB FROM SL
S1 30-AUG
S1 9-SEP
S1 17-SEP
S1 20-SEP
S1 26-SEP
S1 4-OCT
S1 19-OCT
S1 26-OCT
CPUE/2MIN TRAWL
AGE DAYS
AGE DAYS

Figure 28. Age frequency calculated from counting scale circuli for station 2 (S2), by date of collection. Dotted line at 61 days is for comparison.

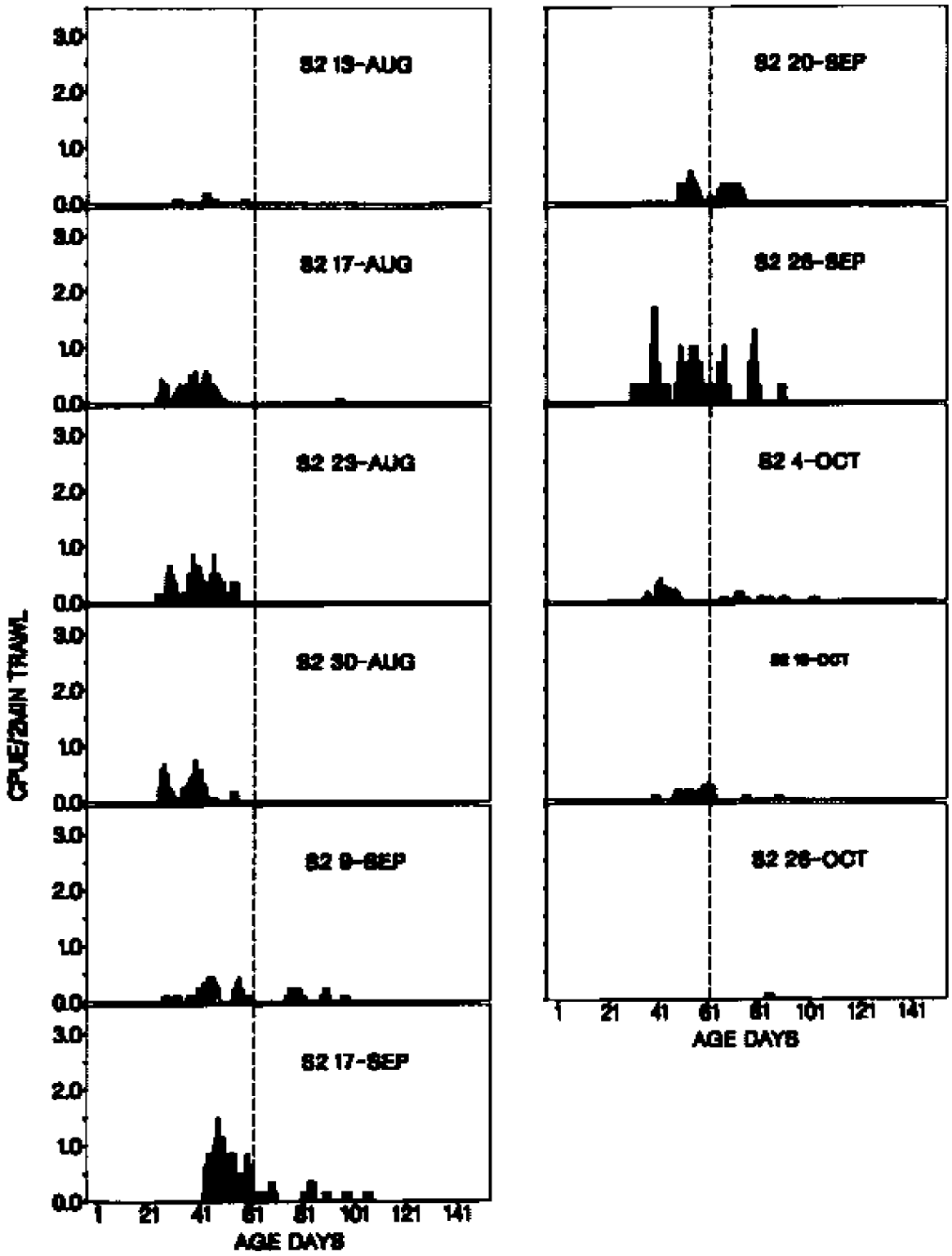

CPUE/2MIN TRAWL
S2 19-AUG
S2 17-AUG
S2 23-AUG
S2 30-AUG
S2 9-SEP
S2 17-SEP
S2 20-SEP
S2 26-SEP
S2 4-OCT
S2 10-OCT
S2 26-OCT
0.0
1.0
2.0
3.0
1
21
41
61
81
101
121
141
AGE DAYS

Figure 29. Age frequency calculated from counting scale circuli for station 3 (S3), by date of collection. Dotted line at 61 days is for comparison.

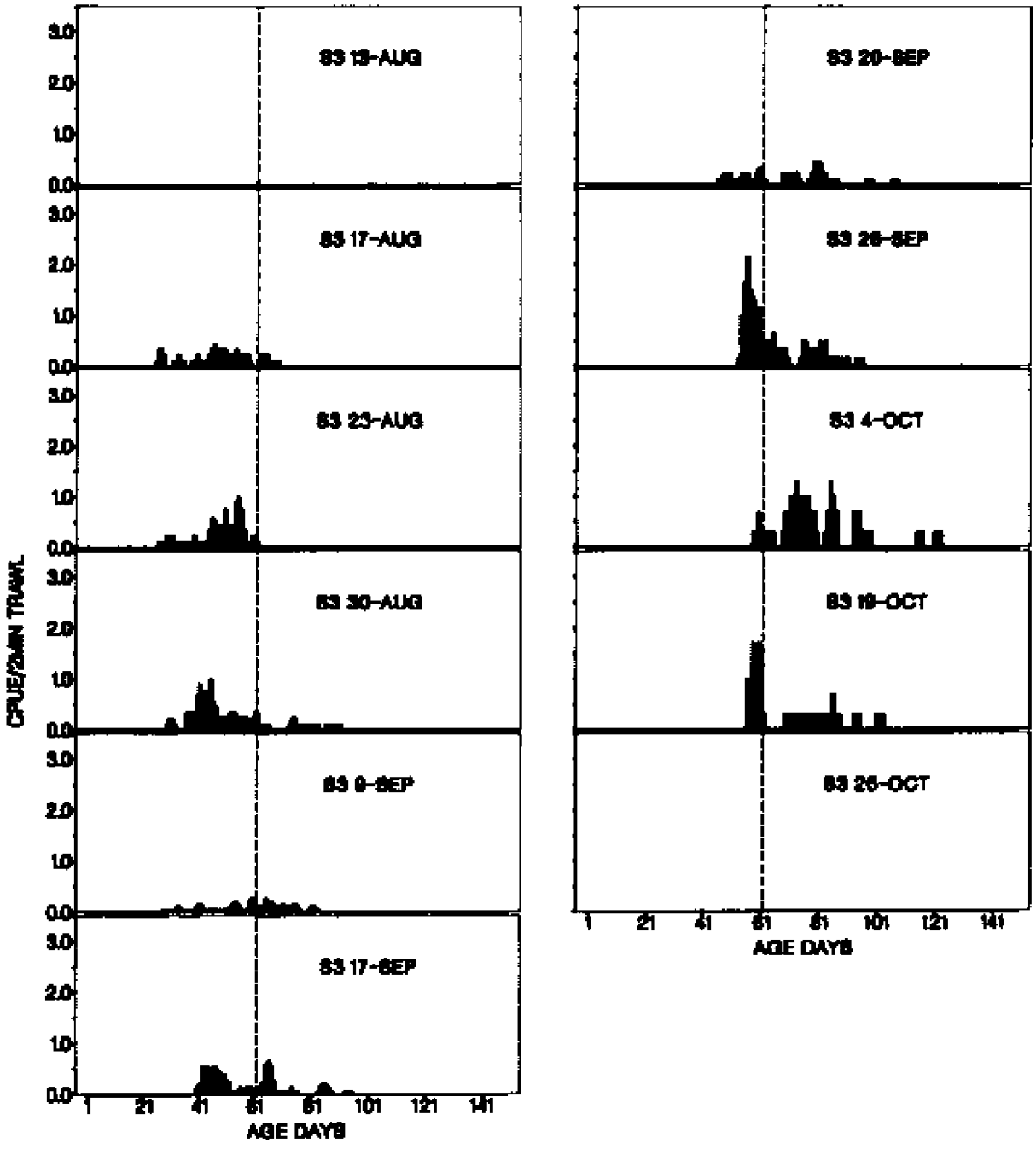

83 13-AUG
83 17-AUG
83 23-AUG
83 30-AUG
83 9-SEP
83 17-SEP
83 20-SEP
83 26-SEP
83 4-OCT
83 19-OCT
83 26-OCT
CPUE/20MIN TRAWL
AGE DAYS
AGE DAYS
0.0
1.0
2.0
3.0
1
21
41
61
81
101
121
141

Figure 30. Age frequency calculated from counting scale circuli for station 4 (S4), by date of collection. Dotted line at 61 days is for comparison.

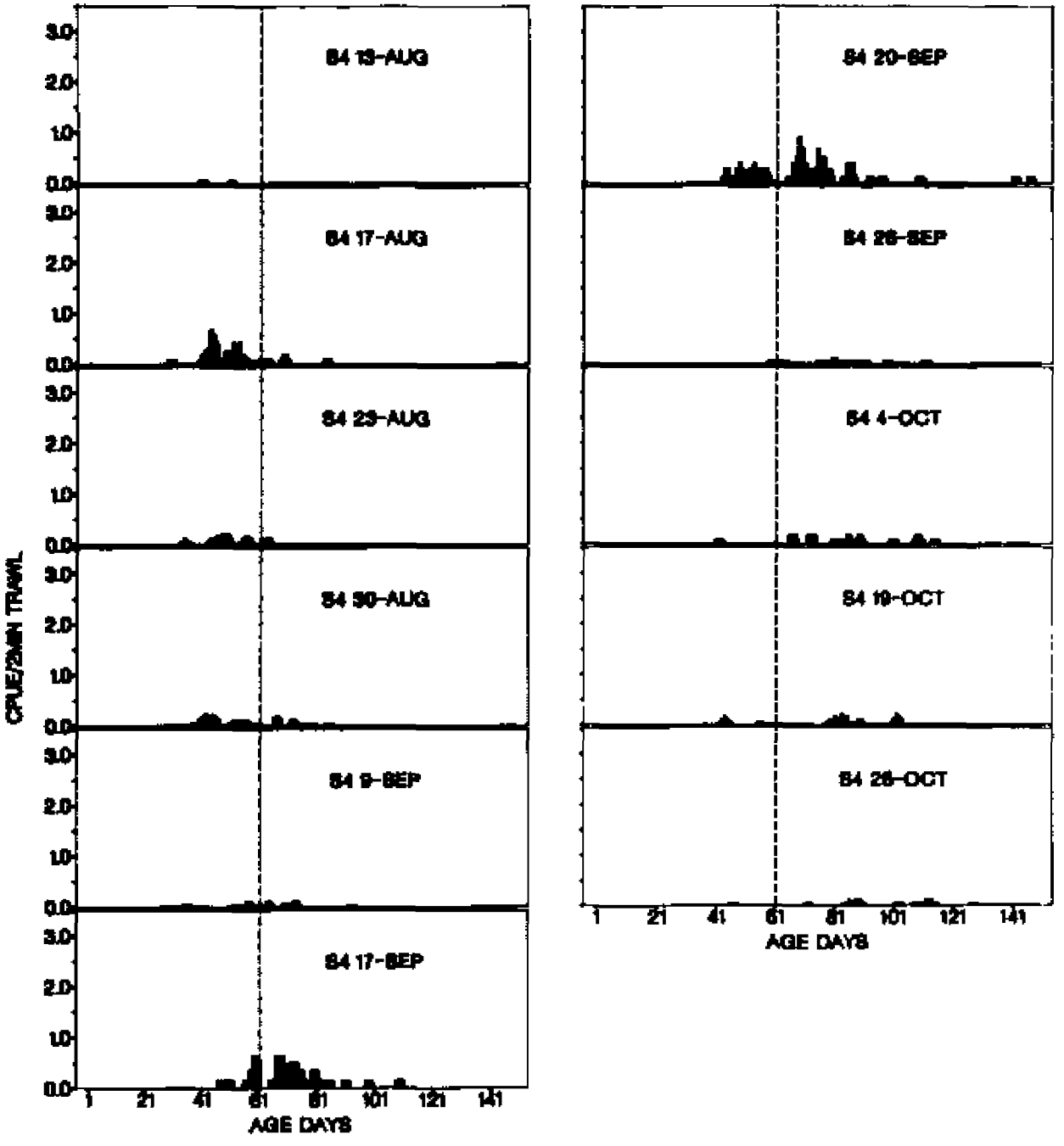

CPUE/2MIN TRAWL
84 13-AUG
84 17-AUG
84 23-AUG
84 30-AUG
84 9-SEP
84 17-SEP
84 20-SEP
84 26-SEP
84 4-OCT
84 19-OCT
84 26-OCT
0.0
1.0
2.0
3.0
1
21
41
61
81
101
121
141
AGE DAYS

Figure 31. Birthday frequency distribution for station 1 (S1) by sample date. The abscissa is divided by days, and starts with 21A=21-April and ends with 85=8-September. Dashed lines separate cohorts.

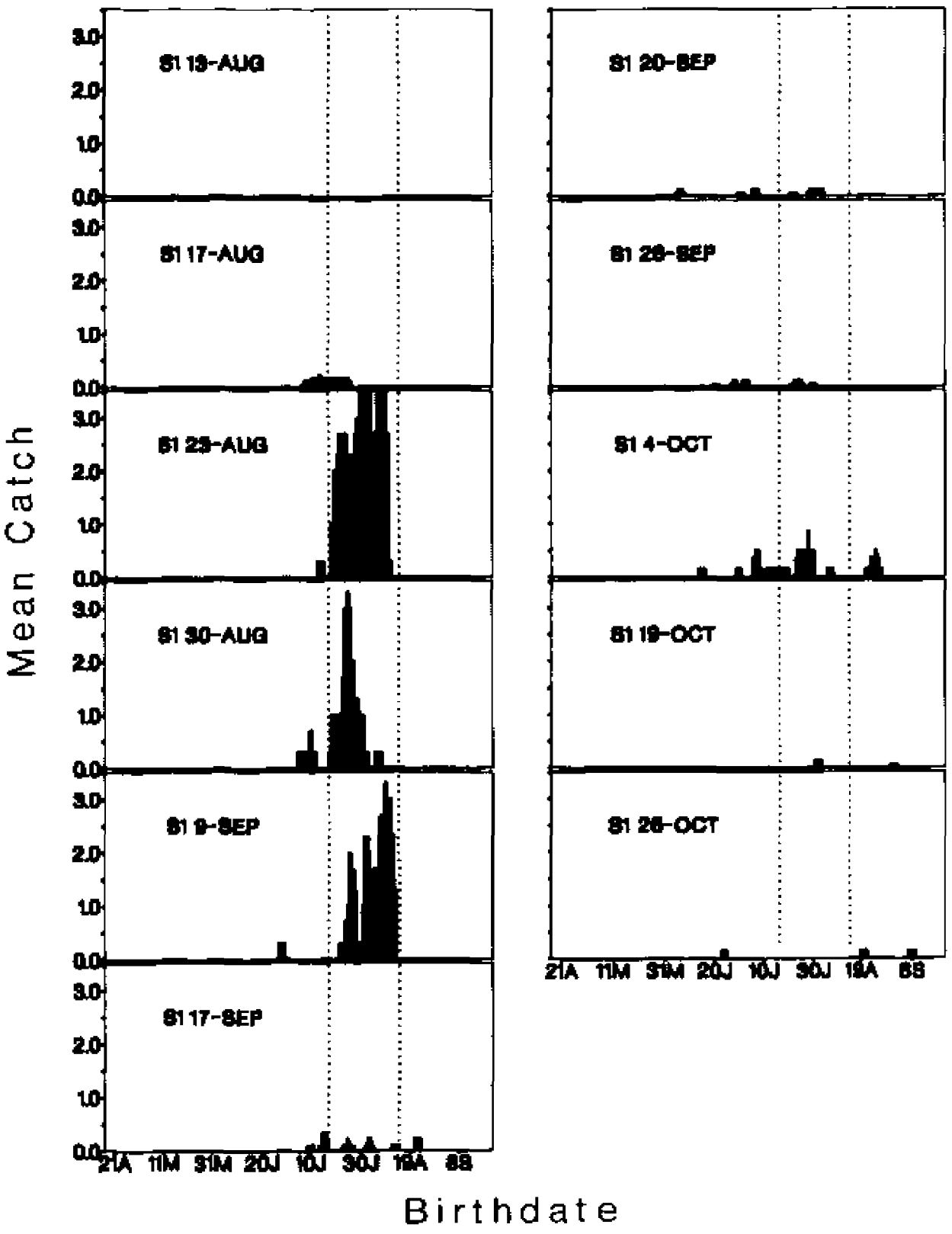

Mean Catch
S1 13-AUG
S1 17-AUG
S1 23-AUG
S1 30-AUG
S1 9-SEP
S1 17-SEP
S1 20-SEP
S1 29-SEP
S1 4-OCT
S1 19-OCT
S1 26-OCT
3.0
2.0
1.0
0.0
21A 11M 31M 20J 10J 30J 19A 8S
Birthdate

Figure 32. Birthday frequency distribution for station 2 (S2) by sample date. The abscissa is divided by days, and starts with 21A=21-April and ends with 8S=8-September. Dashed lines separate cohorts.

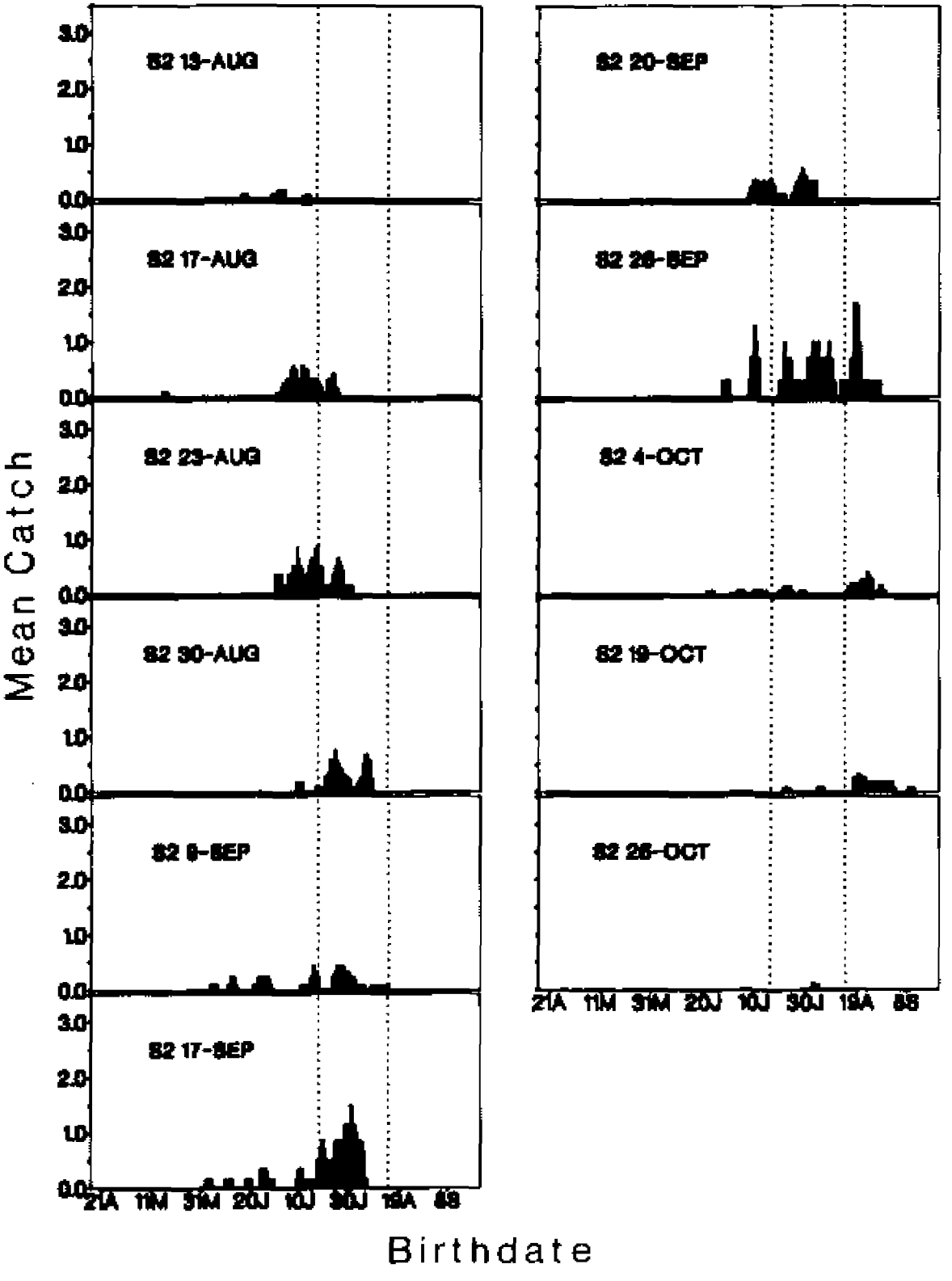

Mean Catch
S2 13-AUG
S2 17-AUG
S2 23-AUG
S2 30-AUG
S2 6-SEP
S2 17-SEP
S2 20-SEP
S2 26-SEP
S2 4-OCT
S2 19-OCT
S2 26-OCT
3.0
2.0
1.0
0.0
21A 11M 31M 20J 10J 30J 19A 88
Birthdate

Figure 33. Birthday frequency distribution for station 3 (S3) by sample date. The abscissa is divided by days, and starts with 21A=21-April and ends with 8S=8-September. Dashed lines separate cohorts.

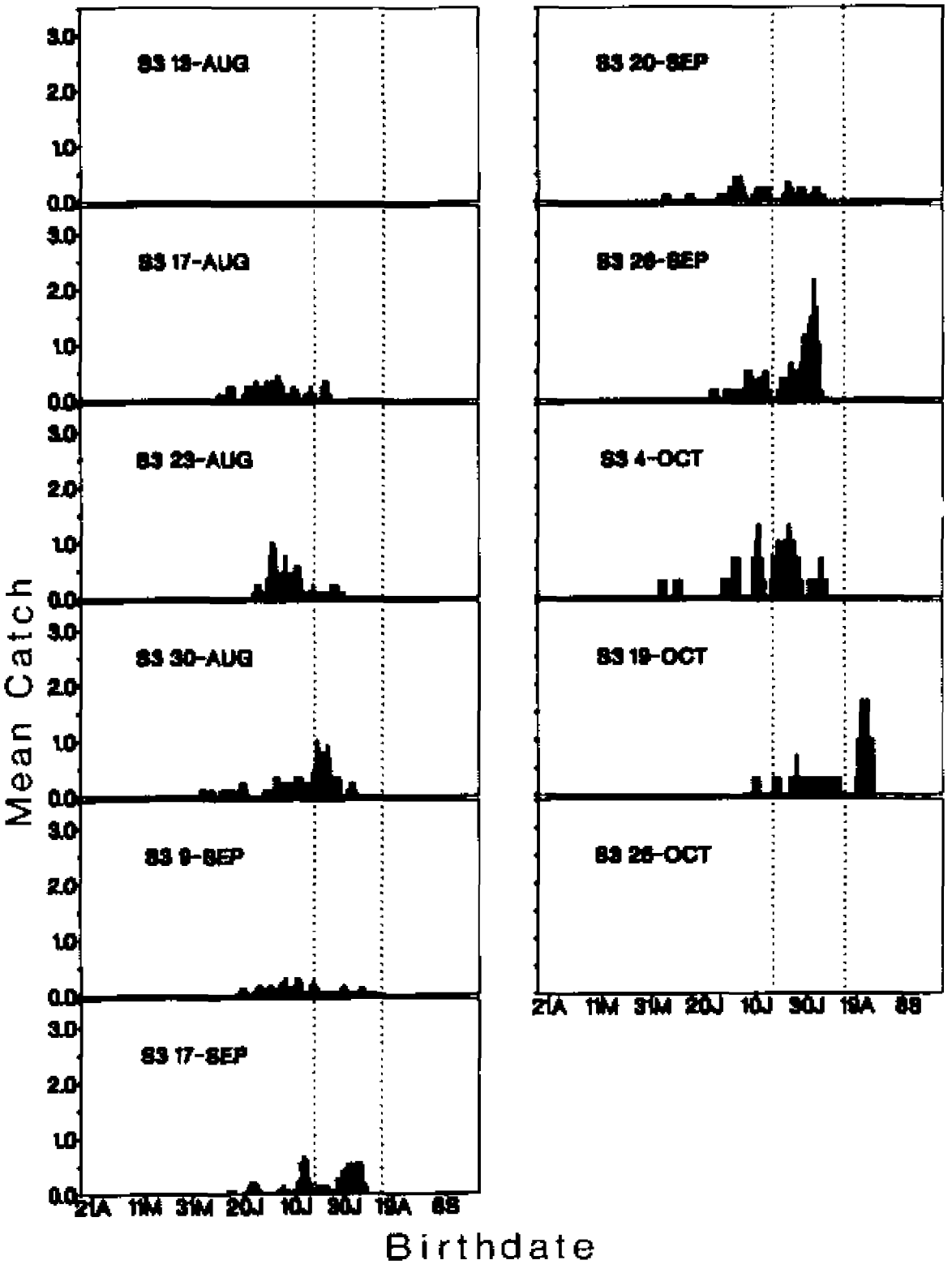
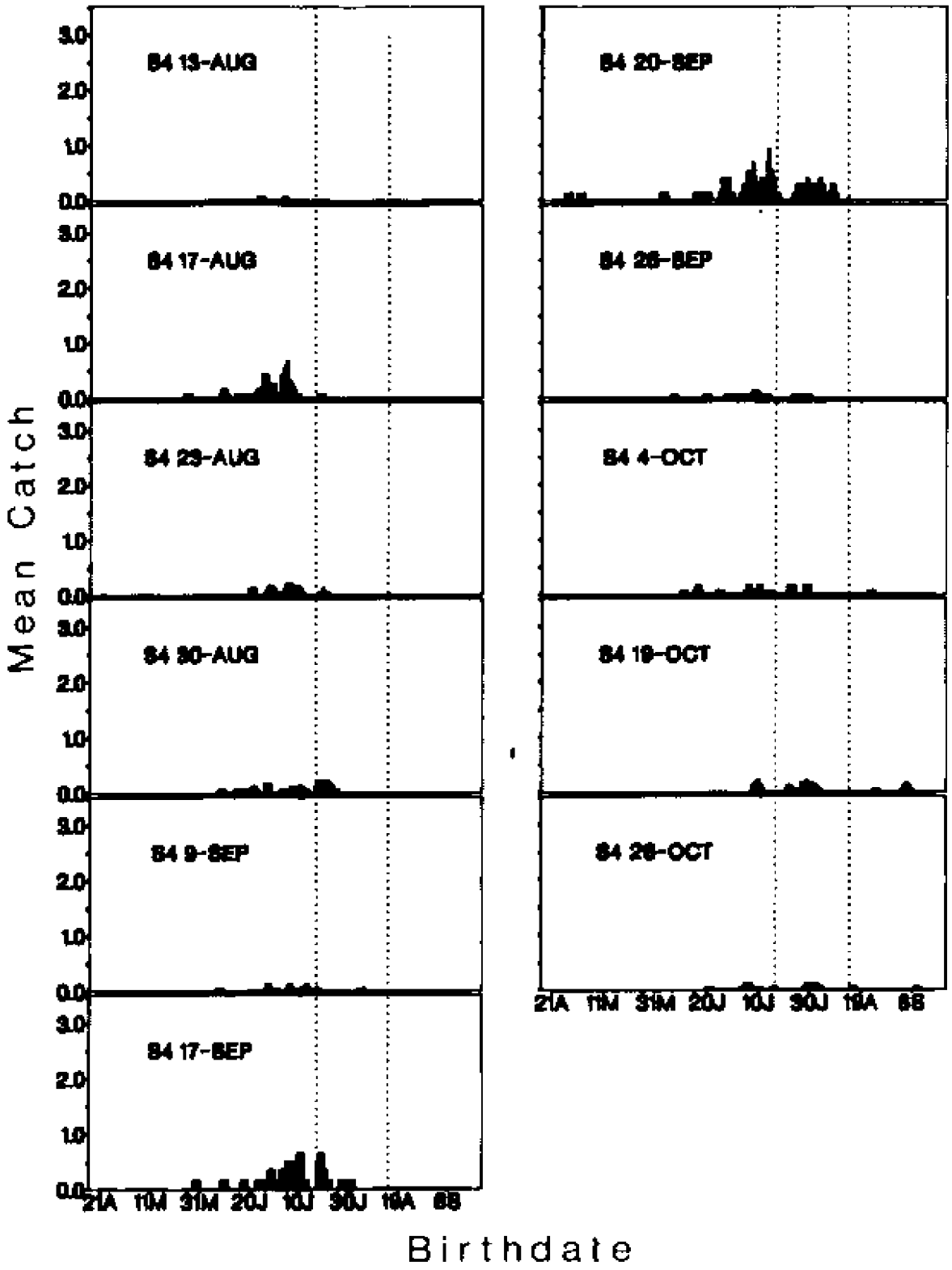

S3 19-AUG
S3 17-AUG
S3 23-AUG
S3 30-AUG
S3 9-SEP
S3 17-SEP
S3 20-SEP
S3 26-SEP
S3 4-OCT
S3 19-OCT
S3 26-OCT
Mean Catch
0.0
1.0
2.0
3.0
21A 11M 31M 20J 10J 30J 19A 8S
Birthdate

Figure 34. Birthday frequency distribution for station 4 (S4) by sample date. The abscissa is divided by days, and starts with 21A=21-April and ends with 8S=8-September. Dashed lines separate cohorts.


Mean Catch
84 13-AUG
84 17-AUG
84 23-AUG
84 30-AUG
84 9-SEP
84 17-SEP
84 20-SEP
84 26-SEP
84 4-OCT
84 19-OCT
84 26-OCT
3.0
2.0
1.0
0.0
21A 11M 31M 20J 10J 30J 19A 8S
Birthdate

APPENDIX

LIST OF APPENDICES

Appendix 1. Standardized abundance data from York River, 1983, by station and date. Fractions are number caught/number of 2 min tows.

		STATION								TOTAL
SAMPLE	DATE	10		9		8		7		TRAWLS
1	13AUG83	2/6	0.3		0.0	6/4	1.5		0.0	10
2	17AUG83	27/4	6.8	28/3	9.3	34/4	8.5	21/6	3.5	17
3	23AUG83	16/6	2.7	34/3	11.3	26/2	13.0	84/1	84.0	12
4	30AUG83	23/6	3.8	42/3	14.0	35/4	8.8	28/1	28.0	14
5	9SEP83	12/6	2.0	34/6	5.7	25/3	8.3	38/1	38.0	16
6	17SEP83	24/2	12.0	49/5	9.8	42/2	21.0	12/3	4.0	12
7	20SEP83	34/2.5	13.6	23/3	7.7	21/3	7.0	13/6	2.2	14.5
8	26SEP83	10/6	1.7	42/2	21.0	33/1	33.0	12/6	2.0	15
9	4OCT83	15/4	3.8	23/1	23.0	27/5	5.4	23/2	11.5	12
10	19OCT83	18/6	3.0	20/1	20.0	20/4	5.0	3/5	0.6	16
11	26OCT83	12/6	2.0	0/3	0.0	1/3	0.3	4/2	2.0	14
TRAWL TOTALS		54.5		30		35		33		

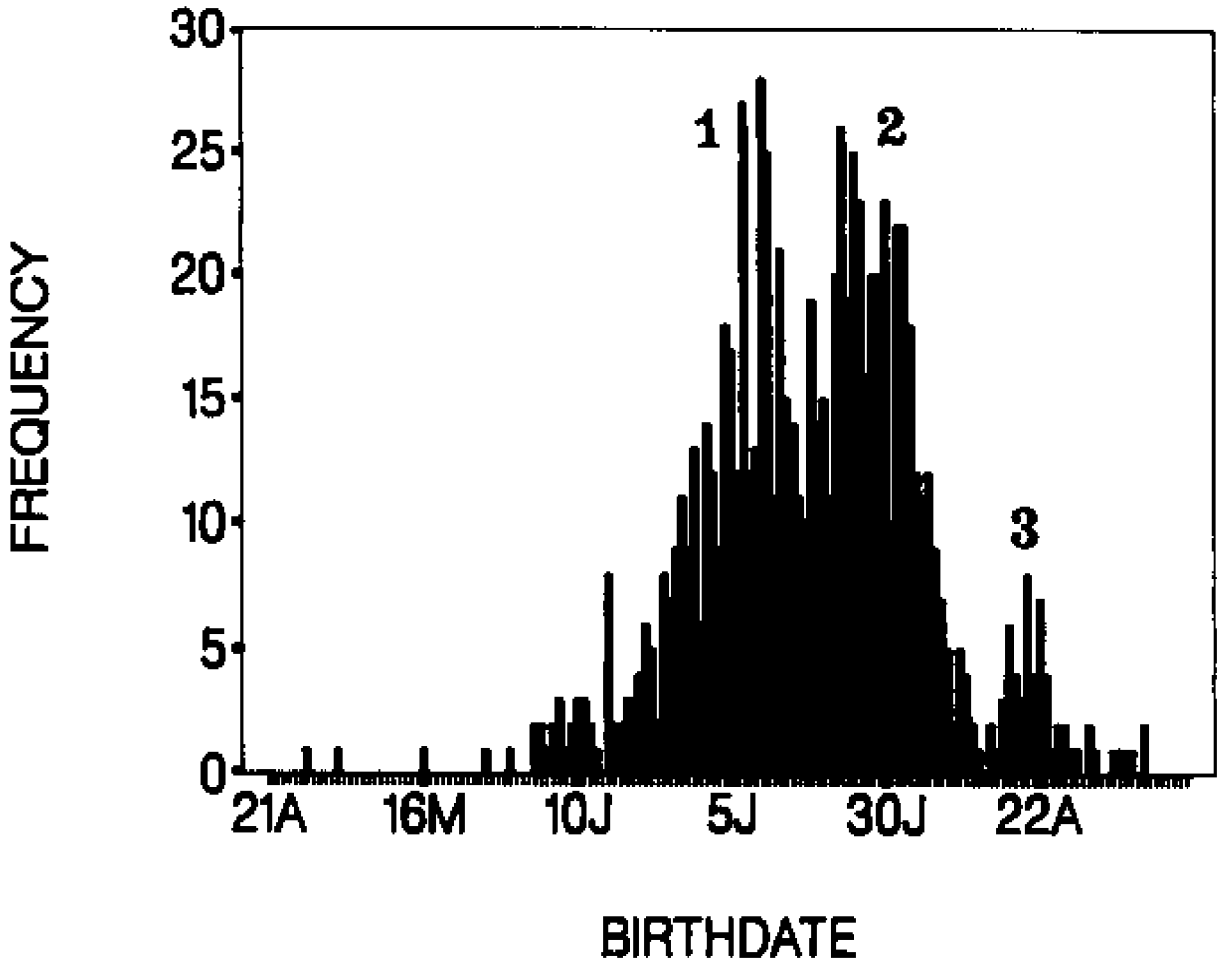
Appendix 2. Non-parametric analysis of variance on rank abundance.

VARIABLE	DF	SS	MS	F VALUE	PR>F
Model	13	3911.01	300.85	2.84	0.009
Date	10	3345.88		3.16	0.007
Station	3	565.14		1.78	0.172
Error	30	3175.49	105.85		
Total	43	7086.50			

Tukey's Studentized Range, a=0.05, DF=30, MSE=105.85. Dates with same letters are not significantly different.

DATE	26AUG	30AUG	17SEP	4OCT	9SEP	26SEP	20SEP	17AUG	19OCT	26OCT	13AUG
GROUPING	A	A	A	A	A	A	A	A	A	A	
				B	B	B	B	B	B	B	B

Appendix 3. Birthday frequency distribution for all weakfish aged by scale circuli counting (845 aged/922 collected) from the York River, VA.


30
25
20
15
10
5
0
FREQUENCY
1
2
3
21A
16M
10J
5J
30J
22A
BIRTHDATE

Appendix 4. Analysis of covariance of growth rates.

SOURCE OF VARIATION	SS	DF	MS	F	Sig of F
Age	245305.8	1	245305.8	23707.3	0.00
Cohort	1149.9	2	574.97	55.6	0.00
Station	169.1	3	56.4	5.4	0.001
Cohort by Age	1474.3	2	737.2	71.2	0.000
Station by Age	309.2	3	103.1	10.0	0.000
Station by Cohort	82.0	6	13.8	1.3	0.238
Cohort by Station by Age	98.5	6	16.4	1.5	0.148
Error	3495.1	821	10.3		

After Analysis of covariance showed significant slope difference:
Tukey test for comparisons among slopes.

Cohort #1

	n=373	SS	DF	MS	
r^2=0.94664	residual	5976.06298	371	16.10799	SUM(x^2)=158956.895
	regression	106024.24526	1	106024.24526	b=0.816701
					inter=-0.687

Appendix 4, con't

Cohort #2

	n=414	SS	DF	MS	
r^2=0.96750	residual	3043.52200	412	7.38719	SUM(x^2)= 98291.527
	regression	90599.79936	1	90599.79936	b=0.960076
					inter=-6.835852

Cohort #3

	n= 58	SS	DF	MS	
r^2=0.94628	residual	304.83683	56	5.44351	SUM(x^2)= 5680.845
	regression	5369.24477	1	5369.24477	b=0.972188
					inter=-4.831972

H_o Cohort 1 = Cohort 2 Tukey Test

$(Sy^2x)p$ = (5976.06298 + 3043.52200)/(371 + 412)

= 11.52

SE = SQRT(11.52(1/158956.895 + 1/98291.527))

= 0.0138

q = (0.960-0.817)/0.0138

= 10.36

DF_p = $SUM_{i=1,k}(n_i-2)$ = (373-2) + (414-2) =

$q_{critical}$ = 0.9539

Reject H_o

Appendix 4, con't

H_o Cohort 1 = Cohort 3 Tukey Test

$(Sy^2x)p = (5976.06 + 304.84)/(371 + 56)$

$= 14.71$

$SE = SQRT(14.71(1/158956.90 + 1/5680.85))$

$= 0.052$

$q = (0.972-0.817)/0.052$

$= 2.98$

$DF_p = (373-2) + (56-2) =$

$q_{critical} = 0.9539$

Reject H_o

H_o Cohort 2 = Cohort 3 Tukey Test

$(Sy^2x)p = (3043.52 + 304.84)/(412 + 56)$

$= 7.15$

$SE = SQRT(7.15(1/98291.53 + 1/5680.85))$

$= 0.036$

$q = (0.972-0.960)/0.036$

$= 0.33$

$DF_p = (414-2) + (56-2) =$

$q_{critical} = 0.9539$

Accept H_o

Appendix 5. Statistical computations of a t-test for significant mortality differences

Cohort # 1		Cohort # 2	
X	Y	X	Y
4	44.1	17	60.7
10	43.3	27	42.5
17	25.7	35	43.5
27	24.4	38	26.0
35	28.2	44	31.3
38	31.3	52	25.8
44	19.3	67	12.5
52	24.2	74	4.3
67	3.1		
74	4.3		
n = 10		n = 8	

$SS_x = 18408 - 368^2/10 = 4865.6$

$SS_{xy} = 6515 - (368)(247.9)/10$

$= -2607.7$

$SS_y = 7836.71 - 247.9^2/10$

$= 1691.27$

$b_1 = -0.536$

$DF_1 = 10 - 2 = 8$

$SS_x = 18292 - 354^2/8 = 2627.5$

$SS_{xy} = 8564.4 - (354)(246.6)/8$

$= -2347.65$

$SS_y = 9879.06 - 246.6^2/8$

$= 2277.6$

$b_2 = -0.893$

$DF_2 = 8 - 2 = 6$

Appendix 5, con't

$RegSS = 1691.27 - (-2607.7)^2/4865.6 = 293.68$

$RegSS = 2277.6 - (-2347.65)^2/2627.5 = 179.99$

$S^2_{yx} = (293.68 + 179.99)/14 = 33.83$

$s_{b_1-b_2} = SQRT\ (33.83/4865.6 + 33.83/2627.5) = 0.14$

$t = (-0.536)-(-0.893)/0.14 = 2.55$

$t_{0.05(2),14} = 2.145$

$t > t_{0.05(2),14}$ Reject $H_o: B_1 = B_2$

Slopes or Mortality rates are significantly different. (ZAR 1984)

VITA

STEPHEN T. SZEDLMAYER

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