AGING REEF FISHES
IN THE SOUTHEAST FISHERIES CENTER

BY

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INTRODUCTION

For eight years scientists at the Beaufort Laboratory of the National Marine Fisheries Service, Southeast Fisheries Center have been studying western Atlantic reef fishes. This research is conducted within the SEFC Reef Fish Program supported by various Center Tasks, including Bioprofiles.

The collecting and analysis of life history samples (age structures, stomachs, gonads, etc.) continues to be an essential component of this Program and involves people at state, federal, and university levels in the Southeast Region. Of all the specific life history projects, age, growth, and mortality have been assigned the highest priority and therefore have received the most effort.

Results of these aging studies have been substantial. Fish have been aged, growth has been measured, mortality has been estimated, and yield/recruit models have been constructed for a few species. Although this information will be used by Regional Fishery Management Councils to develop Management Plans, many questions remain unanswered. The purpose of this paper is to present the results of reef fish aging in hopes of encouraging constructive discussions which will benefit fishery scientists, managers, and reef fishery constituencies.

Research on reef fish in the Southeast Region has undergone a geographic change over the past eight years. The Program has enlarged from a North Carolina-South Carolina study from 1972 to 1976 to include all the east coast from North Carolina through the Florida Keys. Data are also collected from the Gulf of Mexico and Caribbean. It is understandable that for the first few years, age and growth studies were directed at species economically and sociologically important off the Carolinas. Recently more emphasis has been placed on fishes which are important to Gulf of Mexico and Caribbean fisheries.

We have completed, or are completing, studies on 14 species: red porgy, *Pagrus pagrus*; knobbed porgy, *Calamus nodosus*; white grunt, *Haemulon plumieri*; tomtate, *H. aurolineatum*; gray tilefish, *Caulolatilus microps*; snowy grouper, *Epinephelus niveatus*; speckled hind, *E.*

drummondhayi; scamp, Mycteroperca phenax; gag M. microlepis; vermilion snapper Rhomboplites aurorubens; red snapper Lutjanus campechanus; gray snapper L. griseus; yellowtail snapper Ocyurus chrysurus, and gray triggerfish Balistes capriscus. This work has been aided by graduate students enrolled in degree programs at nearby universities. Manuscripts resulting from research on eight of these species have been or will be submitted as partial fulfillment of degrees (two Ph.D and four M.S.) at North Carolina State University, University of North Carolina at Chapel Hill, College of William and Mary (VIMS), and Rutgers University. Several staff members at the Beaufort Laboratory serve as adjunct faculty at these institutions and direct student research.

METHODS

COLLECTION OF FISH

Most fish were obtained from hook and line fisheries; recreational head boats, and commercial handline vessels. Young-of-year and yearlings were collected from a variety of sources - experimental and commercial trawling, seining, and from power plant intake screens and were used to verify the time of annulus formation and the position of the first annulus on the aging structure. For all fish, total lengths were recorded in millimeters and weights in grams or kilograms.

REMOVAL AND PREPARATION OF AGING STRUCTURES

Four types of structures have been evaluated for aging reef fish: otoliths, vertebrae, scales, and spines. Scales were removed from beneath the tip of the posteriorly extended pectoral fin, soaked in a one-tenth aqueous solution of phenol and were mounted dry between two glass slides. Four to six mounted scales for each sample were viewed at 20 to 41 X magnification on a scale projector. Power of magnification was dictated by the size of scales which varied between species. Measurements were made in the anterior field along a line from the focus to the scale margin. Distances in mm from the focus to each ring and to the margin were recorded (Figure 1a).

Otoliths (sagittae) were removed either by making a cross cut in the cranium with a hacksaw thus exposing the earbones, or by opening the otic bulla with a wood chisel and entering the cranium from under the operculum. The latter was used to avoid disfiguring fish which were to be sold. Otoliths were read intact or after sectioning and were then stored dry in vials or envelopes. Whole otoliths were placed in a blackened-bottom watch glass containing clove oil and viewed under a dissecting microscope with the aid of reflected light. Measurements were made from the core to each ring and to the otolith radius (Figure 1b). The selected field of measurement varied between species. For sectioning, representative otoliths of each species were examined microscopically to identify the area where rings were most legible and

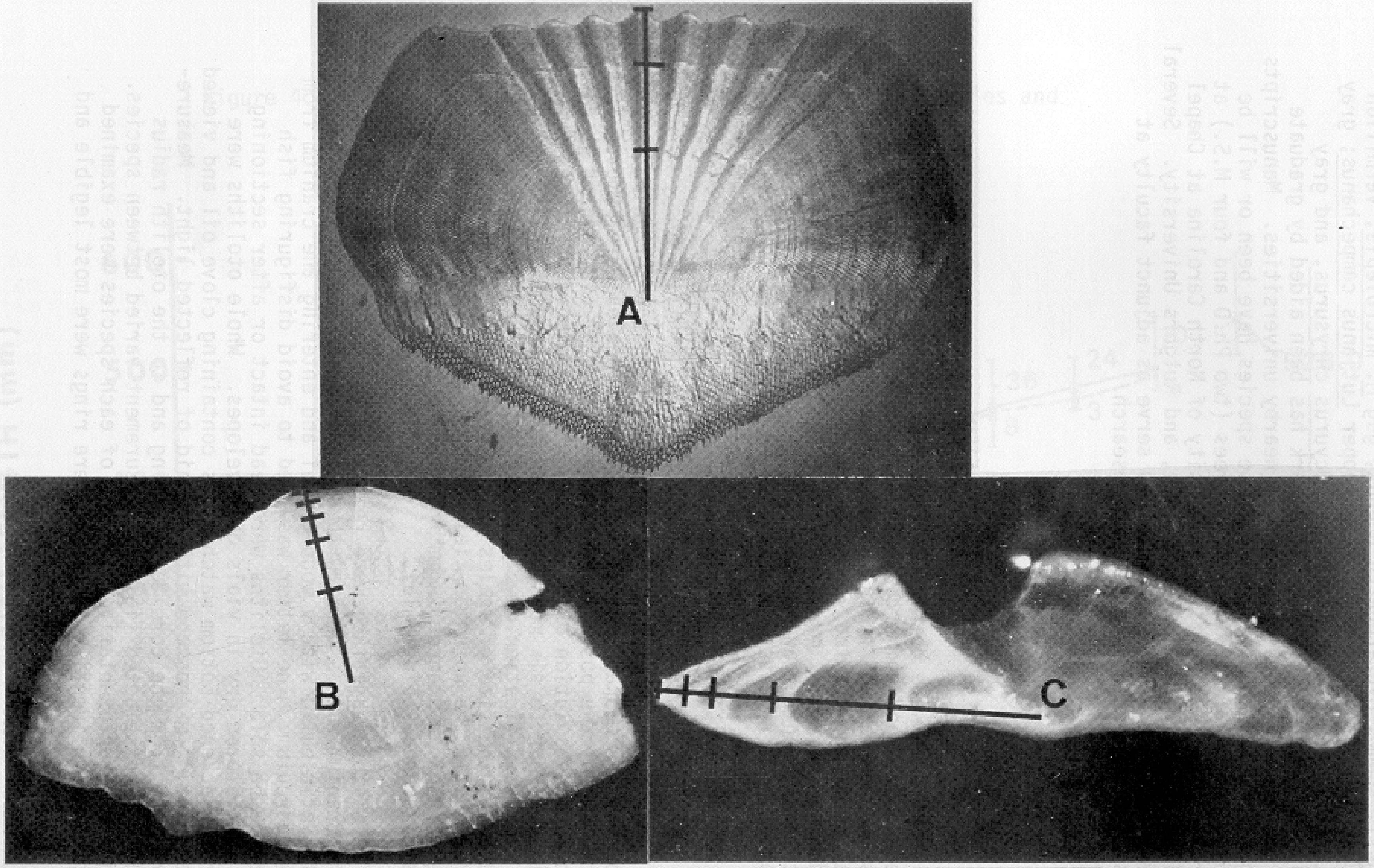


Figure 1. Scale (a); whole otolith (b); and sectioned otolith (c), all from gray snapper.

where erosion of the edge was minimal. Otoliths were then aligned and mounted in a chuck to prevent lateral movement, and sectioned with a Buehler[1/], Isomet 11-1180 low speed saw yielding three, 0.18 mm sections (Figure 1c). The sections were read and measured in the same manner as described above for whole otoliths.

Three or four caudal vertebrate were dissected from the fish, cleaned with a 7% sodium hypochlorite solution, rinsed in water and stained with 0.01% crystal violet solution. After drying, the stained vertebrae were cut in half along the lateral plane with a Dremel[1/] saw. The distance from the centrum to each ring or ridge, and the centrum depth were measured with the aid of a binocular microscope.

Using dorsal spines to age gray triggerfish and related species looks promising (Allyn Johnson, personal communication). The first dorsal spine is removed by cutting at the spine base with metal or bone shears.

EVALUATION OF AGING STRUCTURES

OTOLITHS

Otoliths were preferred for aging most reef fish. Sagittae alone were used to determine age and growth of all groupers, gray tilefish, gray and yellowtail snappers. Otoliths were selected when scales were too small, and therefore not practical, as with groupers and tilefish, or had a very high percentage of regeneration and nonlegibility, as with the gray and yellowtail snappers.

Both otoliths and scales were analyzed together to age red porgy, vermilion snapper, red snapper, tomtate, white grunt, and knobbed porgy. When used with scales, otoliths were read to validate the scale aging technique.

Sectioned otoliths, although more difficult to prepare, were more easily read and measured than whole otoliths. Johnson (unpubl. ms[2/]) found 9% of the yellowtail snapper otoliths had more bands when cross-sectioned than on the surface of the unsectioned otolith. The discrepancy in number of rings identified on whole and sectioned earbones is expected to be even greater for species that live longer than yellowtail snapper, such as _Ephinephelus_ groupers.

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

2/ Johnson, A. Unpublished manuscript. An evaluation of yellowtail snapper hardparts for age determination. National Marine Fisheries Service, Panama City Laboratory, Panama City, Florida. 32407.

A disadvantage of otoliths is that annular markings are much wider on otoliths than the "no growth" annuli on scales, forcing the reader to decide exactly where measurements should be made. Also, the subject of otolith annuli formation - causes, what time of year, and chemical composition of bands - is controversial.

SCALES

Scales were easier to collect and prepare than otoliths or vertebrae, and therefore were sometimes selected over otoliths as the primary structure for determining age. Even then a limited number of otoliths were used to validate scale readings. Scales were successful for aging red porgy, vermilion snapper, red snapper, tomtate, and white grunt, but were useless for gray and yellowtail snappers.

VERTEBRAE

Caudal vertebrae were unacceptable for aging red porgy and yellowtail snapper. Since both scales and otoliths were satisfactory for aging red porgy, vertebrae were not used because they were difficult to remove. Johnson (unpubl. ms[2/]) found yellowtail snapper vertebrae also difficult to prepare, and that agreement between two readers for the same vertebrae was only 26%.

VALIDATION OF RINGS AS ANNULI

Regardless of which structure is used, validation of the rings as annuli is important. Three different methods were used: marginal increment analysis, plotting the length frequencies of the distance from the focus or core to each ring for each age group, and by comparing mean lengths for each age determined from otoliths to those obtained by reading scales. In many instances all three techniques were used in a study.

Marginal increment analysis involves calculating for each month the mean distance from the last ring to the edge. The resulting distribution should be unimodal if one ring per annum is formed (Figure 2). Smaller, younger, fish are preferred for this work since rings are more distinct and measurements more precise.

Frequency distributions of focus-to-ring distances (Figure 3) should reveal occurrence of one mode for each ring, and a consistent location of a specific mode on the X-axis for fish of different ages. Plotting focus to ring distance frequencies generally works well for the first ten years of life, afterwards excessive overlapping obscures the modes.

Another method of validation is to examine two different types of aging structures from the same fish to see if the number of rings counted is the same. In most instances scales and otoliths were not

Figure 2. Monthly margininal increment analysis of red snapper scales with two, three and four rings. The fish were collected from the northern Gulf of Mexico (from Nelson 1980).

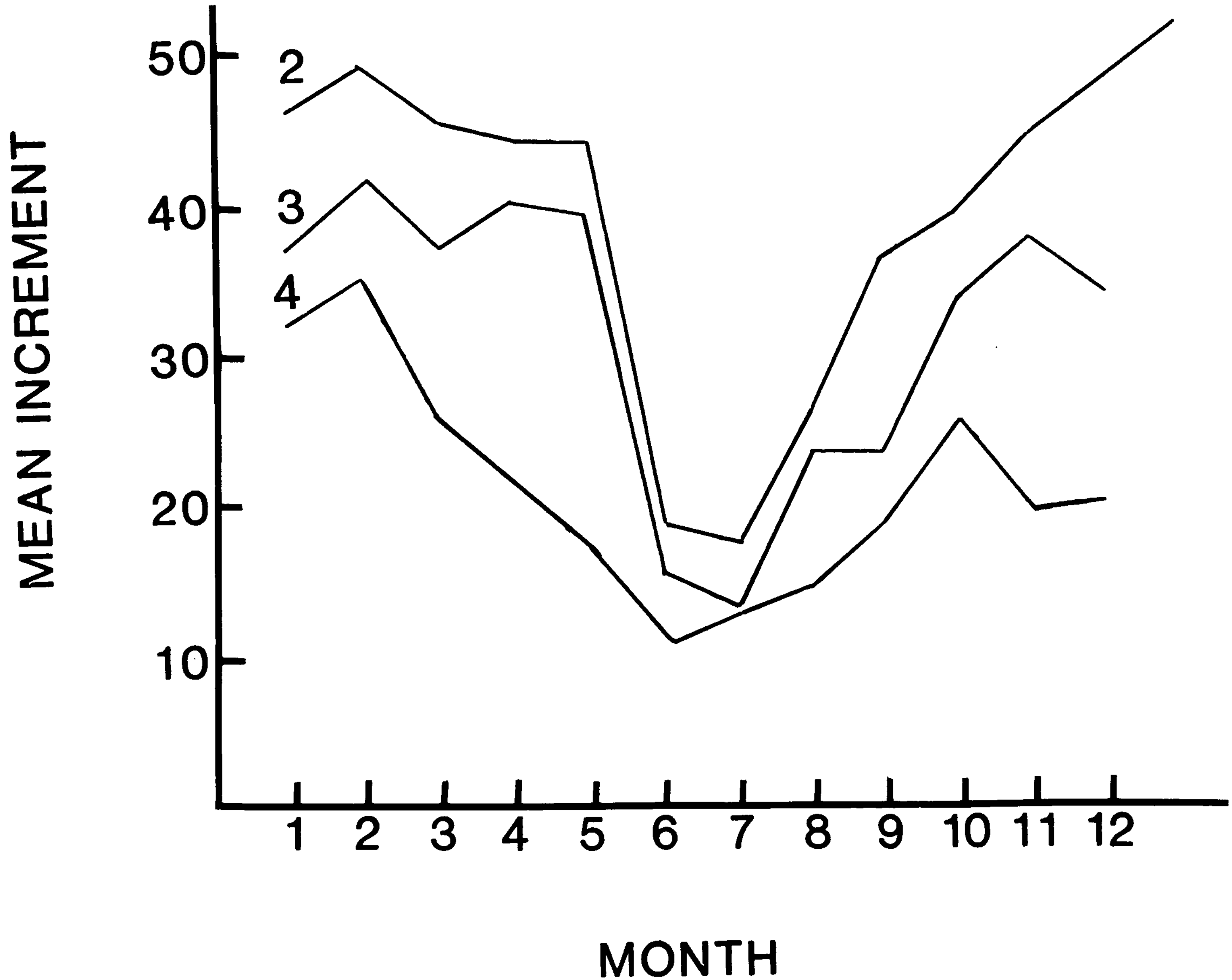
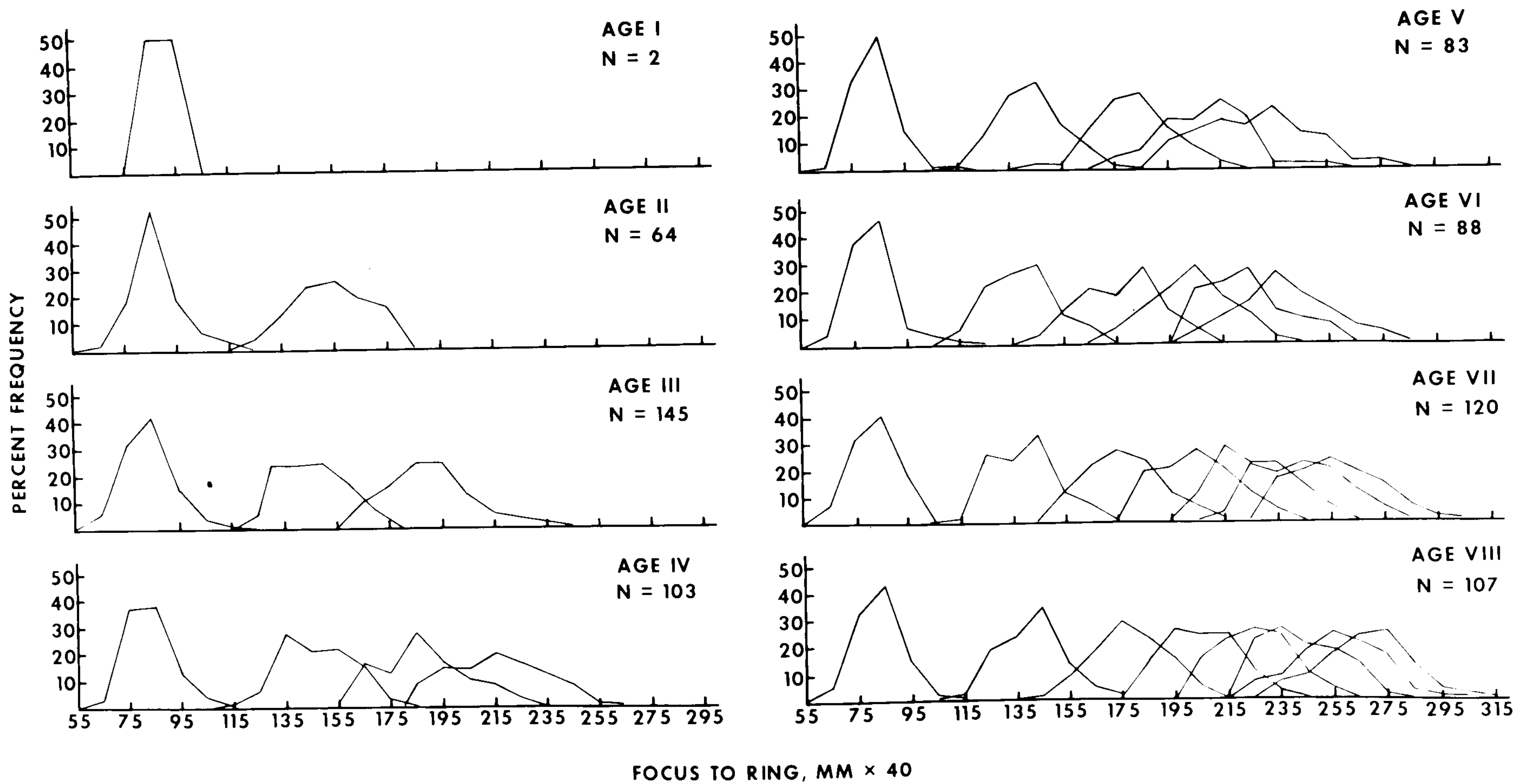


Figure 3. Frequency distributions of white grunt scale focus-to-ring distances (from Manooch 1976).



available from the same fish, therefore comparisons were made between mean lengths for ages from otolith-aged and scale-aged samples of a given species (Figure 4).

Two errors frequently made in aging reef fish have been the ommission of the first annulus or the inclusion of the focus as an annulus. This results, for example, in calling a two year old fish one year old, or a one year old fish, two years old. These errors are particularly common when examining whole otoliths, but also occur while reading sectioned otoliths and scales. The only sure way we had to verify the relative position of the first annulus and the time of its formation was to collect fish which were known to be young-of-year. We then measured the otolith core radius or scale focus radius, thereby eliminating it as an annulus candidate, and then sampled monthly to observe where the first annulus was formed on the structure.

GROWTH

After the aging method is validated the next step is to determine the relationship of body size to aging structure size and subsequently the change in length or weight of the fish over time. We usually describe observed, back-calculated, and theoretical growth patterns.

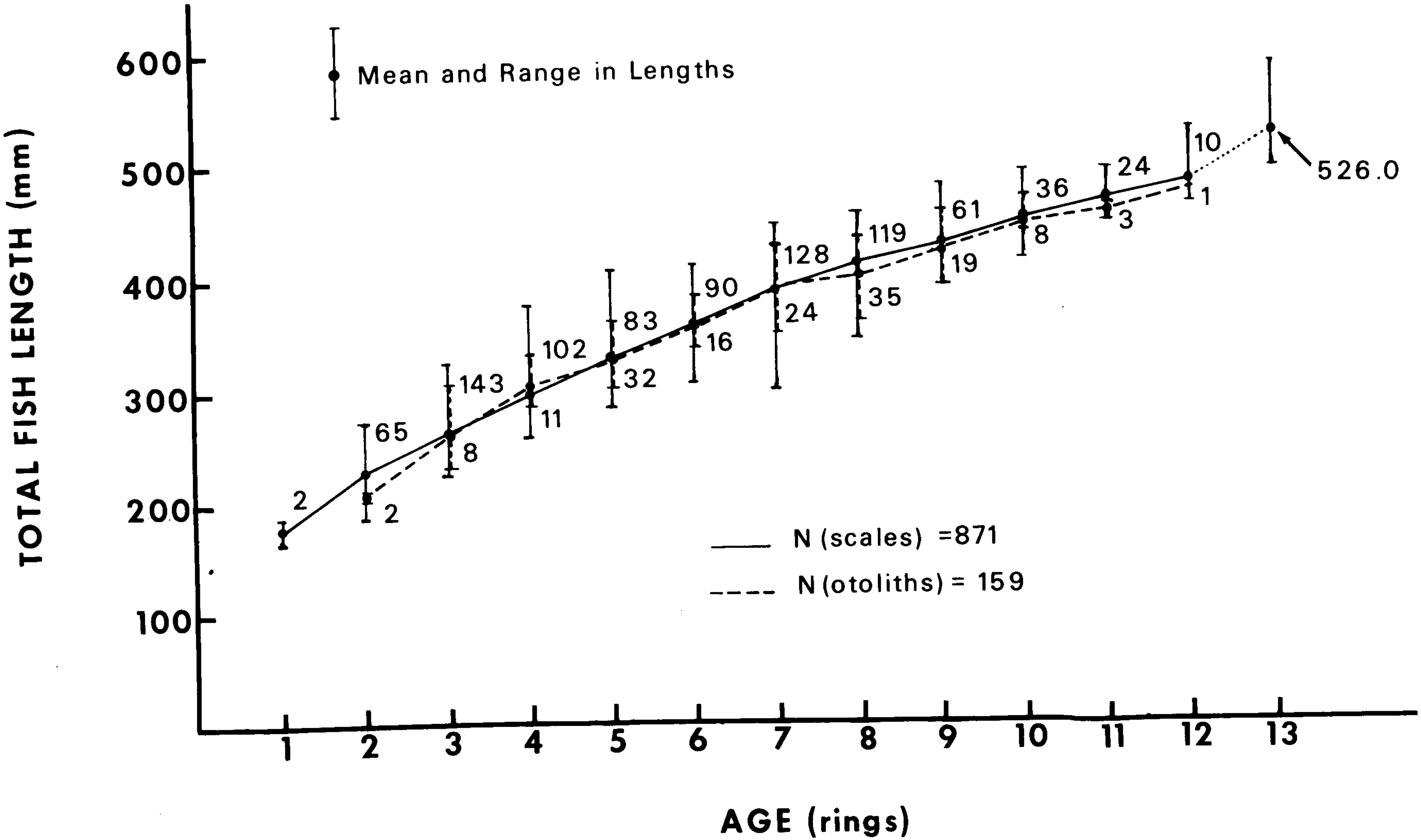
Observed growth is the change in length from the date of annulus formation to the time of capture. Fish size for a particular age therefore is greater for observed age than for back-calculated age. Observed age and growth information is useful to fishermen who wish to know the age of the fish they have caught, and also for the construction of catch curves.

Growth is the increase in length from one annulus to the next and is reported as length at the time of annulus formation back-calculated from length at time of capture. Calculated lengths are used to derive theoretical growth equations and to make comparisons between species, areas, sexes, etc. To obtain back-calculated length at a specific age, we first determined the relation between fish length and the radius of the aging structures by plotting magnified scale or otolith radius of fish length. Usually most fish lengths were concentrated around a relatively narrow size range because of gear selectivity. To reduce this bias subsamples were taken after grouping fish into 25 mm size intervals. The resulting equation usually took the form:

$TL = a+b(R)$, where TL = total fish length, R = otolith or scale radius, a = intercept and b = slope. Occasionally we used log - log regression:

$$\log TL = a+b(\log R) \text{ or}$$
$$TL = aR^b.$$

Figure 4. Observed lengths at age for white grunt aged by scales and by otoliths (from Manooch 1976).



To obtain length at a particular age we substituted the means of the distances from the focus to each annulus for R in the above equations, calculated the mean fish length at the time of each annulus, and then calculated mean growth increment for each age group (Table 1).

Theoretical growth models are useful in estimating yields of fish. Growth parameters such as theoretical maximum attainable size (L_∞), growth coefficient (K), and theoretical origin of the growth curve when growth is fully developed (t_0), may be used in constructing population models. Perhaps the most popular theoretical growth curve is the von Bertalanffy ($\ell_t = L_\infty(1-e^{-K(t-t_0)})$) and is fitted to back-calculated length at age data (Everhart et al. 1976; Ricker 1975). This particular equation also allowed us to make comparisons with results obtained by other researchers.

The growth parameter, L_∞, was first derived by fitting a Walford (1946) line: $\ell_{t+1}=L_\infty(1-k) + k\ell_t$ to back-calculated data where ℓ_t = total length at age t, and k = slope of the Walford line. An initial equation $\ell_{t+1} = a + k\ \ell_t$ is developed. The slope (k) is equal to e^k, thus $K = \ell_n k$. A preliminary value of L_∞ can be obtained by solving the equation:

$$L_\infty = \frac{\text{y-intercept}}{(1-k)} .$$

A second estimate of L_∞ may be obtained by regression annual growth increment (X) against fish length at the beginning of the incremental period (Y) (Jones 1976). The intercept is an estimate of L_∞. To evaluate the two estimates of L_∞, we frequently plotted $\log_e (L_\infty - \ell_t)$ against t; the straightness of the resulting line is dependent upon the value of L_∞. Using trial values of L_∞ ranging from the lowest estimate to one exceeding the highest, we were able to determine the best L_∞, that is the one with the straightest line. The K resulting from the equation was used to determine t_0:

$$t_0 = \frac{\text{y - intercept of natural log line} - \log_e L_\infty}{K} .$$

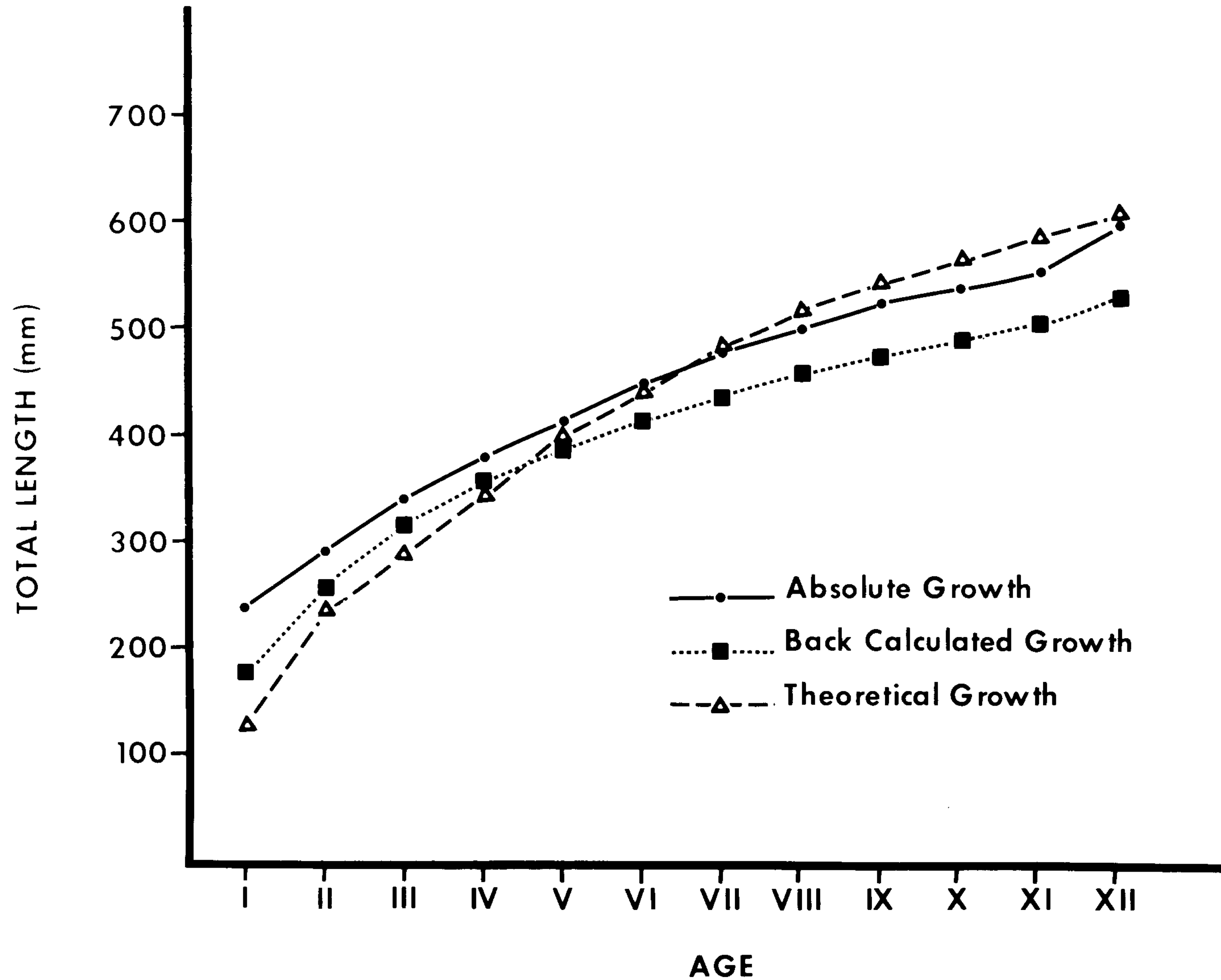
We checked the t_0 value to see if it was biased toward younger or older fish by using the equation $t_0 = t(1/K)\ \ell n\ (1-\ell_t/L_\infty)$ for separate ages (Jones 1976). Observed, back-calculated, and theoretical lengths at age for red porgy are presented in Figure 5.

Computer programs are being evaluated to facilitate the derivation of theoretical growth parameters. We have used SAS Proc NLIN to fit age and length data for red snapper to the von Bertalanffy parameters (Nelson 1980). This program, as well as others, (BMDX 85, SPSS NONLINEAR), uses modified Gauss-Newton, steepest-descent, or Marquardt methods in regressing the residuals on the partial derivatives of the model with respect to the relevant parameters. The iterations converge at the smallest possible error sum of squares. The advantages of the non-linear curve fitting approach are that the procedures are completely reproducible and estimates of the variance assoicated with parameter estimates are available for testing differences in growth curves. Additionally, back-calculated lengths at every year of life from each fish are used in the regressions. This reduces the bias induced by using average lengths at age with unequal sample sizes in the various age classes.

Table 1. Back-calculated total lengths (mm) for snowy grouper collected from the South Atlantic Bight (from Matheson, In press).

Age	Number	Length at time of Annulus Formation																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	5	191																
2	41	206	329															
3	52	203	324	400														
4	79	214	332	405	463													
5	81	211	328	402	462	515												
6	56	214	326	398	459	512	560											
7	45	210	326	401	459	511	556	596										
8	35	214	324	400	458	510	558	601	641									
9	22	199	326	406	462	514	562	605	644	680								
10	17	210	320	404	463	510	555	598	635	669	700							
11	11	214	344	416	475	524	572	613	651	688	722	756						
12	10	206	334	408	466	520	576	621	660	698	730	760	791					
13	9	227	329	404	462	515	563	605	645	678	714	749	778	811				
14	3	243	349	429	495	543	588	632	676	712	752	787	818	854	885			
15	7	202	324	406	475	531	583	632	672	705	734	765	814	842	871	902		
16	3	216	340	416	482	539	588	628	672	712	752	782	814	841	867	894	920	
17	2	207	333	419	466	512	572	632	659	698	738	778	811	894	878	904	931	958
Number of calculations		478	473	432	380	301	220	164	119	84	62	45	34	24	15	12	5	2
Weighted means		210	328	403	462	514	562	605	647	686	721	762	798	832	874	900	924	958
Increment		210	118	75	59	52	47	43	42	39	35	41	32	34	42	26	24	34

Figure 5. Observed, back-calculated, and theoretical growth curves for red porgy (from Manooch and Huntsman 1977).



MORTALITY ESTIMATES

Mortality estimates may be obtained after fish have been aged and if the size or age distribution in the catch is known. Reef fish along the southeastern United States and from the Gulf of Mexico are not fully recruited to hook and line fisheries until at least age two and sometimes as late as age seven (Figure 6). Annual total mortality estimates from catch curves, therefore, were based on fish age two or older. If the $\log_e$ of the age frequency in the catch is plotted on age, the slope of the linear descending right limb of the curve estimates the mean instantaneous total mortality. To calculate mortality rates, we first needed to assign ages to the unaged fish whose lengths had been recorded. We grouped fish of known age by 25 mm length intervals, calculated the percentage of fish of each observed age in each group and used these percentages to estimate the number of fish of each age for the unaged group (Ricker 1975). We estimated the annual total mortality rate for areas and years by species using the regression method, (Beverton and Holt 1957).

REEF FISH GROWTH CHARACTERISTICS

Results of our age and growth research on reef fish have been very predictable. Species studied to date are long-lived, their rates of growth are slow, and their natural mortalities are low. These shared growth-related characteristics (Table 2) are important because they allow one to consider management in a generic sense, based at the community level. An exogenous stress on the fishable reef fish stocks, such as fishing, tends to effect each species similarly whether it is a porgy, grunt, snapper, or grouper (Huntsman and Manooch 1979; Huntsman et al unpubl. MS[3/]).

PROBLEMS AND APPROACHES

Considering the previous discussions it should be obvious that some tropical marine fishes may be aged by annular growth rings on hard parts. There are several problems, however, which we have encountered and deserve further discussion. These difficulties may be grouped into three categories: collection of fish, preparation and examination of hardparts, and interpretation of markings.

Most of the fish referred to in this paper were collected from recreational and commercial hook and line fisheries. There are two problems with these collections, size of fish and season of catch. Young-of-the-year, even one year olds, are excluded from hook and line landings, although these

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[3/] Huntsman, G. R., C. S. Manooch, III, L. L. Massey and C. B. Grimes. Unpublished Manuscript. Yield-per-recruit models of some reef fishes of the U.S. South Atlantic Bight. National Marine Fisheries Service, Beaufort Laboratory, Beaufort, NC 28516.

Figure 6. Catch curves for red snapper caught by hook and line (from Nelson 1980).

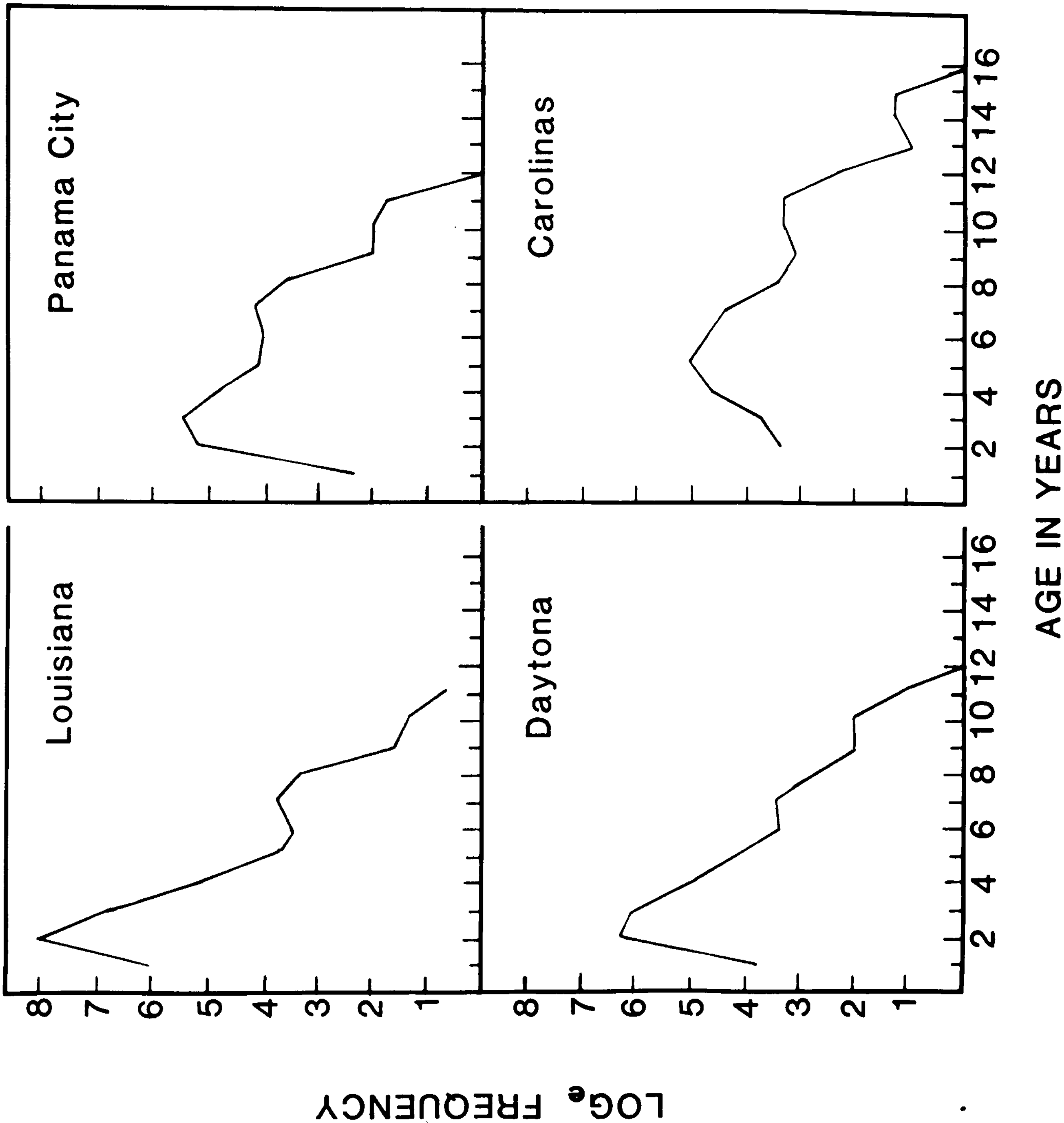

Table 2. Maximum age and growth parameters of reef fishes from different areas. Growth parameters may vary slightly when manuscripts in press or preparation are published.

SPECIES	AUTHORS	Maximum Age	Growth Parameters L_∞	k	t_0
Speckled hind 1/	Matheson (in press)	15	1,105	0.088	-1.92
Snowy grouper 1/	Matheson (in press)	17	1,350	0.063	-2.32
Gag 2/	Manooch and Haimovici (1978)	>13	1,290	0.122	-1.27
Scamp 1/	Matheson (in press)	21	1,090	0.067	-3.91
Gray tile fish 1/	Ross (1978)	15	814	0.137	-1.03
Red Snapper 3/	Nelson (1980)	16	975	0.060	-0.00
Red Snapper 4/	Nelson (1980)	16	941	0.170	-0.10
Gray Snapper 5/	Manooch and Matheson (in press)	18	890	0.101	-0.32
Yellowtail Snapper 5/	Johnson (unpub. MS.)	14	--	--	--
Vermillion Snapper 1/	Grimes (1978)	10	627	0.198	+0.13
Tomtate 2/	Manooch and Barans (in prep)	9	310	0.220	-1.28
White grant 1/	Manooch (1976)	13	640	0.108	-1.01
Knobbed porgy 1/	Horvath (in prep)	17	459	0.212	-1.75
Red porgy 1/	Manooch and Huntsman (1977)	15	763	0.096	-1.88
Gray trigger fish 3/	Johnson (in prep)	--	--	--	--

1/ North Carolina and South Carolina

2/ South Atlantic Bight

3/ South Atlantic and Gulf of Mexico

4/ Gulf of Mexico

5/ South Florida, east and west coasts

young fish are essential to aging studies. The problem of size exclusion may be overcome by obtaining specimens from fisheries using a different gear, for instance trawl; by using experimental gear, for instance seining; or by investigating incidental collecting methods, such as power plant intake screens. It is essential that fish obtained from non-fishery sources be eliminated from catch curve analyses.

Samples from seasonal fisheries do not lend themselves to marginal increment analysis or other age validation techniques. Most vessels in the south Atlantic fish from about April to the end of November because of inclement weather the rest of the year. Samples from December to April were not usually available. Supplementary sampling by scientific cruises was required to provide aging structures on a year-round basis.

Another sampling-related deficiency was that sex of fish was usually unknown. This resulted when commercial landings where involved and fish were gutted at sea, or where samplers were not allowed to dissect fish which were to be sold. At other times gonads were preserved but sex was not identified on the sample sheet. Thus the sex of the fish would remain unknown until the preserved material was examined, possibly years hence. The Bioprofiles Task and Reef Fish Program should design and coordinate sampling procedures which will provide adequate sizes and sexes of fish, from the desired geographical areas and on a seasonal basis.

Several difficulties encountered were related to the preparation of hard parts for aging. Otoliths, for example, reveal much variation between species regarding focus clarity and size, and also the sectioned plane best suited for taking measurements. Structural inconsistancies necessitate close examination of otoliths representing a wide range of sizes for each species to be studied.

Large, thick scales also present problems. For some species such as red snapper and red porgy, scales of older, larger fish were too thick to read directly. Plastic impressions were occasionally required to facilitate readability.

Also, with older fish, sample sizes are small and rings are very close together. Therefore, deviations from mean annular measurements may be magnified. Care must be taken in counting and measuring rings for older fish.

Properly defining slow growth zones and rapid growth zones on otoliths, and determining the cause(s) of annulus formation were the two major problems in the interpretation of age structure markings. The literature is confusing. One writer identifies the hyaline band as the fast growth zone, while another refers to the opaque band as that of rapid growth. Both use reflected light. Occasionally authors are confused, and use both terms interchangeably in the same publication. The subject of basic chemical identity of the otolith rings does not escape this confusion. One researcher labels opaqueness as organic, yet another calls it inorganic. The point is that terminology should be standardized. Opaque represents fast or slow growth, and is either primarily protein, (organic), or calcium salt derivative (inorganic).

Factors which affect the timing of annulus formation are important. At first, our studies with the red porgy (Manooch and Huntsman 1977) and gag grouper (Manooch and Haimovici 1978) seem to indicate that even slight depressions in water temperature were sufficient to suppress somatic growth and cause the formation of annuli. Both of these species spawn in late winter or early spring. Our later research on red snapper (Nelson 1980) and gray snapper (Manooch and Matheson in prep.) suggests that markings on otoliths of these species are formed when water temperatures are elevated in late spring and summer. Both species spawn during summer. We now have an indication that what once was perceived as a temperature controlled phenomenon may actually be related to reproduction. The role of reproduction, particularly hermaphroditism, in the growth of reef fish should be studied in more detail as well as other endogenous rhythms which I believe act in tandem to form annuli on the hard parts of fishes.

RESEARCH REQUIREMENTS

Future age and growth research in the SEFC may continue successfully by methodically progressing through lists of important species. Each year two or three species could be selected, and by utilizing techniques outlined in this paper, age, growth, and mortality would be estimated. However, more emphasis should be placed on unstudied species from the Caribbean and South Florida, and also on stocks in the Gulf of Mexico. Russell Nelson's (1980) work with red snapper indicates that the accuracy of growth and yield models may be improved by analyzing data by geographical area for any given species.

Personally, I believe we need to do more than merely continue extant studies. From the standpoint of scientific challenge, as well as that of fisheries management, we must add depth to our work - investigate the processes - physiological, behavioral, and ecological - which regulate growth. Several recent papers present new concepts and methods which may be applicable in meeting our goals.

Causes of accelerated and depressed rates of growth may be studied by examining daily growth increments on fish hard parts. Brothers, Mathews and Lasker (1976) looked at daily increments on otoliths from temperate and tropical species up to six years of age and found them useful for measuring daily growth. Once determined in the laboratory, daily growth may be evaluated in terms of impact by environmental changes such as temperature, turbidity, and pollution. Studying daily rings may also prove effective in measuring the influence of reproductive cycles on fish growth. Fish held in the laboratory might have their otoliths labeled, be injected with gonadal stimulating hormones, and be allowed to complete spawning. Otoliths would then be removed from the fish and daily growth measured before, during, and after spawning. Field experimentation would follow. Perhaps one of the most applicable uses of daily growth increment studies would be to correlate spawning time with environmental factors such as moon phase, tide, weather fronts and barometric pressure, etc. Also, the early life history - the transformation from a pelagic existence to the demersal stage - could be followed.

Two other methods of measuring growth, ^{14}C labeled glycine uptake (Ottaway 1978; Ottaway and Simkiss 1979), and RNA/DNA ratios (Bulow 1970; Haines 1973; Buckley 1979; Haines 1980) show promise. Both of these new methods allow the measurement of instantaneous growth. And, although they do not give an indication of specific age, they could, by measuring instantaneous growth throughout the year, establish the effects of temperature flux, turbidity, densities of fish, structual heterogenity, etc, on the growth of fish populations. Data could then be used to generate models which would consider the factors mentioned above.

ACKNOWLEDGMENT

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