Final Project Report

to

Arizona Game and Fish Department
2221 Greenway Road
Phoenix, Arizona 85023-4399

Contract KR92-00310-LNR G20019-A

A PRELIMINARY STUDY OF UTILITY OF DATA OBTAINABLE FROM OTOLITHS TO MANAGEMENT OF HUMPBACK CHUB IN THE GRAND CANYON

by

Dean A. Hendrickson
University of Texas
Texas Natural History Collection R4000 - PRC176
Austin, TX 78712-1100

June 13, 1997

Table of Contents

INTRODUCTION 1

SPECIMEN COLLECTION AND OTOLITH PREPARATION AND INTERPRETATION METHODOLOGIES 5

STUDIES OF ADULT HUMPBACK CHUBS 8

STUDIES OF THE YOUNG OF THE YEAR AGE CLASS 9

VALIDATION OF DAILY PERIODICITY OF INCREMENT FORMATION 11

EFFECTS OF TEMPERATURE ON OTOLITH INCREMENT FORMATION 12

GROWING PERIOD FOR HUMPBACK CHUB 13

STUDIES OF ELEMENTAL AND ISOTOPIC COMPOSITION OF OTOLITHS 13

BIBLIOGRAPHY 20

TABLES 61

Table 1 - Numbers of humpback chub specimens used in this study by estimated annual age and river of capture. 62

Table 2 - Numbers and estimated dates of first lapillus increment formation for humpback chub deermined to be young of year (y.o.y. or age 0+) by calendar year and river of collection. 63

FIGURES 64

Figure 1. Size distribution of humpback chub specimens used in this study. 65

Figure 2. Lengths and estimated ages of all post young of year humpback chub specimens used in this study. 66

Figure 3. Frequencies of year classes (based on estimated ages) in overall sample of humpback chub. 67

Figure 4. Lengths and estimated ages of all young of year humpback chub specimens used in this study. 68

APPENDIX A - LIST OF ALL SPECIMENS FROM WHICH OTOLITHS WERE EXAMINED IN THIS STUDY 69

APPENDIX B - LIST OF OTHER SPECIMENS PROVIDED TO THE AUTHOR BY AGFD BUT

NOT USED IN THIS STUDY 73

APPENDIX C - INTERIM PROJECT REPORT OF FEBRUARY 5, 1993 79

INTRODUCTION

This study was initiated with the objective of studying various aspects of the physical and chemical structure of otoliths of humpback chub from the Grand Canyon of Arizona, and primarily from the Little Colorado River (LCR). These studies were to shed light on the utility of otolith studies for improving knowledge of the life history of this endangered species, and to evaluate the potential application of these techniques to questions posed by resource managers.

Whole fish specimens, skeletons, or preserved heads of specimens were provided to the author by a diversity of Arizona Game and Fish field crews who collected from 1989 through 1993. The author, with assistance of Dr. Ed Brothers, extracted, prepared and examined otoliths. Data analysis and reporting was the sole responsibility of the author.

Specifically, the study was to obtain age estimates (years of age) from otoliths of 50 selected skeletonized adult specimens of *Gila cypha* collected from the Grand Canyon by Arizona Game and Fish Department in 1989 and 1990. It was also to obtain age estimates (days of age) for 100 selected young-of-the-year (y.o.y.) *Gila cypha* collected during the same and subsequent years.

Age estimates for y.o.y. were predicated on the assumption that increments counted in the otoliths were deposited daily, and that increment counts could thus be translated to days of life since the date of first increment formation (generally within the first few days following spawning). Since that

hypothesis had not been specifically tested in this species, the study also was to test the hypothesis that increments form on a daily basis, both in the field and in hatchery experiments.

Since at least some humpback chub appear to move across a typically strong thermal gradient at the interface of mainstem Colorado River (MCR) waters and the discharge of the LCR, which is generally much warmer than MCR, it was hypothesized that this transition might lead to the formation of marks, both physical and chemical, in otoliths and that these marks might be used to reconstruct individual life histories with respect to timing of this inter-river movement. Though studies conducted since initiation of the present study {9017} have recently made significant contributions toward documentation of movements of adult humpback chub in the mainstem Colorado, still very little is known of movements of y.o.y. It had been hypothesized that if swept out of the LCR into the mainstem Colorado, the transition might be lethal or have other deleterious impacts on y.o.y. survival and growth. A mark in otoliths that unambiguously conveyed information about extent and timing of movements across this inter-river interface, could thus be valuable in furthering understanding of population dynamics and movements. It was thus proposed to search for such marks in otoliths and to conduct experiments to study the effects of temperature changes on otolith structure.

The original study design also called for an analysis of the feasibility of determining annual growth period duration from otoliths of post young-of-the-year individuals of *Gila cypha* for all growth periods throughout the life of specimens.

At the time of study design, there was considerable discussion and application of chemical analyses of otoliths in the literature of fishery management and stock identification. Studies at this time indicated considerable promise for the techniques, and likely applicability to reconstruction of detailed individual life histories of humpback chub. It was hypothesized that individuals that moved across the MCR-LCR temperature and water quality gradient would deposit a chemical/structural signal in their otoliths that reflected this transtion from one river to the other. Since the temporal structure of otolith deposition and specimen birth date could be recovered from the otoliths as well, the absolute date of the movement event, and fish size at the time, might be accurately recoverable as well. It was therefore proposed to carry out analyses of micro-spatial (=chronological) variation in elemental composition in otoliths of 20 selected individual *Gila cypha* specimens from the Grand Canyon for evaluation of the utility of such techniques for reconstruction of movement history of individuals. In addition it was hoped to compare total elemental composition among otoliths of 5 selected individual specimens of young-of-the-year *Gila cypha* captured in the Little Colorado River, otoliths of 5 hatchery-reared young-of-the-year *Gila cypha*, and otoliths of 5 selected *Gila cypha* suspected or known to have moved between the Little Colorado River and mainstem Colorado River in the Grand Canyon as a means of investigating the effect of these diverse environments on otolith composition.

An accidental spill of isotopes into the LCR drainage {9018} was thought to potentially provide isotopic signatures in otoliths. If some of the isotopes characteristic of the spill were found in otoliths, their presence might serve as an unambiguous marker indicating time spent in the LCR. It

was therefore proposed to determine the isotopic composition of a subsample of the same (or comparable) specimens used for microchemical composition studies. Since otolith isotopic composition had been indicated in other studies to be highly correlated with ambient temperature, isotopic compositional changes during the temporal sequence of otolith deposition thus might also reflect inter-river transitions. Specimens from experiments designed to determine the effects of ambient temperature on otolith increment deposition were therefore to be examined for isotopic composition as well in an attempt to better understand the effect of temperature on isotopic composition of otoliths.

In the course of these studies a bibliography of literature relevant to methods and problems of estimating age and growth of *Gila cypha* and chemical composition of otoliths as related to application of otolith chemistry to reconstruction of the environmental history of individuals was compiled and is provided with this report. Though this bibliography can hardly be claimed to be comprehensive since the literature in this field has become very extensive, it should serve as a starting point for future researchers interested in otolith studies. Finally, the appendices of this report provide an inventory of all specimens of *Gila cypha* from the Grand Canyon used (and not used) in this study, and the earlier interim report on early results from this study (less the bibliography, which has been updated in this report). Some questions answered in that report, such as comparisons of ageing techniques using the asteriscus and opercle, are not reiterated here, and the figures provided there amply illustrate all otolith structural features and variations discussed in this report.

SPECIMEN COLLECTION AND OTOLITH PREPARATION AND INTERPRETATION METHODOLOGIES

All specimens were collected from the Little Colorado River and mainstream Colorado River in Grand Canyon by various crews of Arizona Game and Fish employees between 1989 and 1993, and were subsequently provided to the author. Most adults were captured in hoop and trammel nets, as well as by angling, while fry and juveniles were taken primarily by seining and sometimes minnow traps and dip nets.

Adults were prepared as skeletons in the field by removal of most flesh and were dried in gauze bags in the usually hot and dry field conditions which typically assured rapid desiccation. Total lengths of specimens were measured prior to this preparation, and for most adults, TL was converted to SL for data analysis and report purposes. This conversion was accomplished with the equation SL=0.34+0.848*TL. Though developed in this study from a series of preserved sub-adults collected for this study, and data as available on adults (see Appendix C), this relationship was later found to be very similar to the independently developed and subsquently published relationship, SL=0.822*TL {9107}, which was derived from a much larger sample of adults.

Despite sacrifice of adult specimens used in this study, sex determinations were typically done in the field by external means which later proved error prone {9017}, rather than by dissection and gonadal inspection. Sex determinations associated with specimens used in this study are therefore

suspect, and questions regarding any type of sexual dimorphism were not addressed. Sexes were pooled in all analyses described here.

Skeletons were cleaned in dermestid colonies and otoliths were removed from skeletons or retrieved from specimen trays after falling out of skulls during the preparation process. The tiny size of humpback chub otoliths often led to retrieval of incomlete sets of pairs of otoliths, with some being lost during specimen preparation. On the basis of analyses done in the early phases of this project (Appendix C), opercles and asterisci were eliminated as potential recorders of accurate, retrievable data on ages, and all otolith analyses reported here were done on the lapillus. Choice of this otolith is in general agreement with other otolith ageing studies on Ostariophysans {8421}.

Larval, young-of-the-year (juvenile) to sub-adult age classes were collected in 1990 and later years. Whole specimens were preserved in 95% ethanol in the field and otoliths later extracted in the lab. Standard lengths were measured with digital calipers (+/- .01 mm) following preservation. Sex determination in these young fish was generally not possible and many were provided to the author with guts and gonads removed or as heads only (in which case Total Lengths had been taken by field crews). Otoliths were extracted from larval fishes by teasing them away from surrounding tissues with needles under a dissecting microscope with polarized transmitted light. In larger specimens, otoliths were removed with forceps or needles following excision of the roof of the skull. The number of otoliths from these age classes that was usable in this study was decreased somewhat by otolith decalcification resulting from dilution of preservative in samples in which specimen mass

was great relative to volume of preservative. A limited number of other otoliths was unavoidably lost or destroyed in handling and preparation.

Otoliths were mounted in a diversity of media on petrographic microscope slides and ground and polished by hand to thin sections, generally following published methods {8421}. Grinding was done with a variety of abrasive papers mounted on plate glass and alumina polishing compound. Some of the smallest specimens required no grinding or polishing, but it was found that increment counts in specimens with greater than about 20 increments was generally facilitated by light grinding and polishing. Larger specimens required double grinding to obtain a viewable thin section through the core. In y.o.y. lapilli requiring sectioning, this was typically done on the frontal plane. This sectioning plane was chosen as the most convenient for the morphology of these tiny otoliths and because most required only minor grinding on the convex (dorsal) side. Consequently, loss of edge increments to grinding was rarely observed and this technique provided complete growth sequences. Lapilli of adults, as a result of allometric growth, required sectioning on the sagittal plane to assure complete growth series.

All age estimates reported here are consensus (mean) estimates of two otolith readers, the author and Dr. Ed Brothers. Each reader counted increments at least twice. Generally, counts of the two readers were in close agreement, but in cases of major discrepancies of interpretation between readers, the author deferred to Dr. Brothers' extensive experience with otolith studies. Technical considerations of otolith increment counting precision and conversion of counts to age estimates have been

thoroughly reviewed {8419, 8423}.

All carcasses, skeletons, and associated mounted otoliths from this study remain at University of Texas at Austin, Texas Natural History Collections (TNHC http://www.utexas.edu/depts/tnhc/.www/fish/).

The large collections of museum specimens of humpback chub collected since the 1940's could not be used for otolith studies since formalin in which these were almost invariably preserved acidifies and quickly dissolves otoliths.

STUDIES OF ADULT HUMPBACK CHUBS

Lapilli from 69 sub-adult and adult (age > 0+) specimens were examined (Table 1). Most of these were determined to be from the 1+ age class. Only 12 specimens of the > 0+ age group were from the MCR (11 of these in the 1+ age group), and 57 were from the LCR (Table 1, Figure 1).

Estimated ages of humpback chub examined are presented graphically in Figure 2, for all specimens estimated to be > 0+ years old. Size variation at each age is great. Age 1+ fish ranged from about 25 mm SL to 108 mm SL. Sample sizes were markedly smaller for older age groups, but to illustrate the extent of size variation, specimens estimated to be 6+ years old ranged from about 130 mm SL to 305 mm SL, and estimated ages of specimens within about 20 mm SL smaller and larger than the

largest 6 year old ranged from 6 to 18 years old. Unfortunately, as mentioned earlier, data on sex of most sub-adults and adults was lost in the process of skeletonization in the field, so it's impossible to determine how much of this size variation may be related to sexual dimorphism.

The oldest specimen, estimated to be 22 years old, was 391 mm SL. Since it was taken in 1989, it probably represents the 1967 year class. The frequency distribution of year class representation in the overall sample is intriguing (Figure 3). Although sample size is small and sampling was not necessarily random, nor effort equal across all years, the data are suggestive of a 7 to 8 year periodicity in year class strength. The years 1967, 73-76, 81-83, and 90-93 appear to be peaks in the year class frequency distribution, while specimens representing the 1968, 69, 70, 78, 79 and 86 year classes are absent from the sample.

STUDIES OF THE YOUNG OF THE YEAR AGE CLASS

A total of 94 young of year (y.o.y. or age 0+) specimens were aged using lapilli. Twenty one of these were from the MCR, 17 from relatively close to, or above the LCR (River Mile 44.2 to 74.46), while 4 were taken far below at RM 122.10 and from RM 192.3 to 193.85. The remaining 73 were captured in the LCR from 10 to 12,517 m above the MCR.

Growth rate in y.o.y. appears highly variable. Sample size is too small and within-year variation too

great to allow serious comparisons of growth rate among years, but the pooled sample (Figure 4) illustrates a probably significant difference in slope of the growth equation between specimens taken in the MCR and those taken in the LCR. Individuals in the LCR attained 25 mm SL by 60 days after formation of the first increment in the lapillus, whereas 25 mm SL MCR fish had > 70 lapillar increments. LCR fish in the 25-34 mm SL range all had fewer than about 68 lapillar increments, whereas MCR fish of the same size range had 75 to 142 increments. A notable exception to this pattern is a large y.o.y. taken in October 18, 1990 in the LCR. Its length of 47 mm SL was verified and the otolith increment count was clearly between 190 and 200, making it anomalously large and old as compared to the rest of the sample of age 0+ fish. This is not especially surprising given its late date of capture. The next earliest capture date in any calendar year for which samples are available was 90 days earlier in mid-July of the following year (Table 2), but if growth rates in the LCR, as indicated by the many specimens < 35 mm is extrapolated beyond 35 mm, the size of this "anomalous" individual would be reached at about half of its apparent age. Unfortunately, due to the lack of specimens between 35 and 50 mm SL, there are no data on growth rates through this size and age range, leaving it conceivable that there may typically be a marked population-wide slowing of growth after 35 mm. Location of capture of this specimen, in the LCR only a few hundred meters above the MCR, make the hypothesis that this specimen had spent time in the colder MCR, seem tenable, and this may have slowed its growth. In fact its position in Figure 4 is more consistent with the growth trajectory extrapolated from specimens captured in the MCR

Presumptive daily growth increments are clearly visible under light microscopy in lapilli of the smallest specimens examined and during the earliest portions of otolith growth, these can generally be easily and precisely counted. Increment interval, however, becomes increasingly small with increasing age, sometimes resulting in considerable difficulty resolving increments and counting them without extensive specimen preparation. Some specimens displayed interesting rapid transitions of otolith growth rates (see Plates in Appendix 2 of Interim Report of February 5, 1993, included here as Appendix C), however, and these sometimes made increment counts exceedingly difficult. There seemed to be a tendency for such problems and irregularities in otoliths, possibly representing fluctuating and stressful environmental conditions, to be more prevalent in specimens from the MCR, however, sample size from the MCR is small and no firm conclusions may be drawn.

VALIDATION OF DAILY PERIODICITY OF INCREMENT FORMATION

Two approaches were taken to validate daily increments, but as described in the interim report (Appendix C) difficulties were encountered in each. It was not possible to repeat experiments reported in Appendix C, and consequently validation of daily periodicity of increment formation was not obtained in this study.

Despite failure to rigorously test the hypothesis that lapillar increments counted in this study form with daily periodicity, circumstantial data tend to support this conclusion. Back-calculations of date

of first increment formation (assuming that single increments are formed daily) generally match anecdotal data from field researchers regarding dates of apparent spawning activity in the LCR. Growth rates of y.o.y. estimated in this study are also very near those described in other studies on ontogeny of humpback chub {9019}. As such it seems highly likely that the increment counts reported in this study do equate to ages in days. It should be pointed out, however, that some otoliths, particularly those from the MCR, show signs of sub-daily increments. Though an experienced otolith reader may be able to discriminate these from daily increments, they easily confuse and complicate increment counts.

EFFECTS OF TEMPERATURE ON OTOLITH INCREMENT FORMATION

The experiment described in Appendix C (movement of caged individuals between LCR and MCR) was intended also to address the question of how temperature affected otolith increment formation. Apparent failure of that experiment was described in Appendix C and above. Repetition of this experiment in a hatchery environment with natural light and temperature cycles, and large sample sizes, is recommended.

GROWING PERIOD FOR HUMPBACK CHUB

Increasing otolith thickness and narrowing increments as growth slows in later years, make resolution of daily increments in later years of life difficult. Increments remain clear in thin sections viewed under light microscopy however, and it wsa possible to count increments in growth periods ranging from the first year of life through at least the sixth year. The value of such data is questionable, however, since winter zones (in which increments can not be counted) and growth zones intergrade. It is therefore not possible to accurately count increments, and thus days of life since first increment formation, beyond the first winter, nor an increment counts in each growth season following the first winter be considered to be .accurate reflections of the length of that growing season.

With larger sample sizes, it may be that unique patterns of otolith increments might be found in some years which could be useful to confirm the year of any growth zone containing such unique patterns, and thus confirm age determinations, but sample size in this study was not adequate to pursue such possibilities.

STUDIES OF ELEMENTAL AND ISOTOPIC COMPOSITION OF OTOLITHS

At the time the proposal for this study was written (1991), otolith microchemistry was receiving

considerable attention in the literature and there was much optimism regarding the utility of otolith chemistry data in applied fisheries management. Applications of this new technology using electron microprobe analyses (as proposed to be employed in this study) to re-construct environmental histories of individuals were appearing in the literature at a high rate. Though these were typically from estuarine environments, the unique chemical and temperature gradients humpback chub were surmised to pass through at the mouth of the Little Colorado River provided what seemed the perfect opportunity to apply the technique in freshwater systems, and personal contacts with early experts in the field provided encouragement that these new tools could be successfully applied in this system.

Within a few years, however, doubts were surfacing regarding the utility of this new technique. Jones {8842}, reviewing the Otolith Composition session of the 1993 Symposium of Fish Otolith Research and Application at Hilton Head, South Carolina, indicated that the technique had gone through the "Period of initial excitement" stage of her Research Tool Paradigm model in the late 1980's and early 1990's, and had just entered the "Realization of Major Problems and Limitations" stage which led into the "Retrenchment Stage" which she described as follows:

> ...If the problems are major, then a period of retrenchment or even abandonment occurs. At this point, talks and papers appear that illustrate inadequacies of the new tool (microprobe analysis). Even so, some scientists still see merit in the approach, but note that the tool or technique is not yet sufficiently refined....

> Papers presented in this session fit reasonably well into this research model. The use of electron probe microanalysis to quantify elements in otoliths and other hard parts is an example of a relatively new technique in fish ecology that has been enthusiastically applied to problems of migration and stock identification, but whose limitations are now being widely discussed....
>
> These applications of electron-probe microanalysis demonstrate that although it is quite useful in quantifying large changes in chemical environments, it is less useful with more subtle change.

These findings by others seemed to corroborate the difficulties experienced in this study when attempting to correlate the few microchemistry data sets that were obtained from humpback chub otoliths with otolith structure. Other investigators were having similar difficulties in more controlled studies, and it appeared clear that there was considerable imprecision in the data from the microprobe.

Thus, in the two years following the development of this study based on the relatively inexpensive electron microprobe used in initial studies of otolith chemistry, that technique had come under severe criticism and was generally concluded to be inadequate for most applications, including even those in estuarine systems with fishes passing between marine freshwater environments. It was obvious that more precise techniques would definitely be required for application in more dilute freshwaters, even relatively highly mineralized waters like the Little Colorado River.

Following demonstration of inadequacies of earlier analytical techniques, otolith chemistry researchers turned to vastly more expensive technologies, such as laser-ablation ICPMS (inductively-coupled mass spectrometry), but offers to utilize samples from this study in early testing of this promising equipment met only with technical difficulties related to calibrations at the precision levels required, and with general equipment failures.

Moreover, there is great diversity in otolith size among fishes, and humpback chub otoliths are exceedingly small in comparison to those that had been used in most other studies of otolith chemistry. While state of the art micro-scale sampling with tools such as electron probes and even ICPMS was adequate to chemically sample what equated to short temporal sequences of otolith growth in larger otoliths of other species, the same absolute resolution proved inadequate in this application. Highest attainable resolutions, which sampled several days of otolith growth in larger species, when sampling humpback chub otoliths produced samples which were composites of otolith growth regions extending across months, not days.

As a result of the serious questions posed in the literature and high cost and unproven nature of newer technologies, attempts to carry out the otolith microchemistry analyses originally proposed in this study were indefinetly postponed. Attempts to obtain analyses using the promising newer, and more expensive, laser-ablation ICPMS with the severely limited budget for this project were unsuccessful, and the few data sets from the wave dispersive electron microprobe were rejected.

Such discouraging results were not uncommon in other contemporaneous otolith studies as pointed out by Thresher {8841} in his overview of the Otolith Composition session of the 1993 Hilton Head Otolith conference:

> ...As pointed out by Ed Brothers in his session summary, otolith studies have often not lived up to their initial promise; analysis of otolith microstructure, for example, has proven a valuable tool for life-history studies but also a tool limited in applicability by sometimes poor resolution of structure and by the physiological factors that constrain that structure. The papers on otolith chemistry and composition reflected a pervasive sense of unhappiness with the limits of existing techniques, and most papers focused on attempts to develop better, or alternative, means to obtain information from otoliths....
>
> In the rush to develop analytical techniques and to push to the limits the information that can be gleaned from otolith composition, three problems need to be recognized and addressed. Failure to do so risks discrediting of the field even before it gets off the ground.
>
> First, biologists are not physicists. Over a dozen, very different methods are currently available to analyze otolith composition, all differing markedly in their resolution, accuracy, and biases. Because they generally do not fully understand the

sampling and statistical characteristics of the analytical machines they use, too often biologists fall into an uncritical, "black box" mentality (otoliths in, composition out). The result is predictable. Already, erroneous data have entered the mainstream literature. Critical methodological studies on both the analytical techniques and the statistics applied to otolith data must be undertaken before we are overwhelmed by simple (to a nuclear physicist) errors of interpretation.

Second, the complexity of the analytical and the statistical problems involved in analysis of otolith chemistry renders us all novices and prone to repeating independently each other's mistakes. this reason, quality, rapid communication among research teams is essential at this critical, uncertain stage in the development of the field. This symposium, and an international workshop on otolith chemical analysis we recently hosted in Australia, are a good start that we would all benefit from seeing continued.

And finally, we need ultimately to temper our enthusiasm for the field with the recognition that otoliths are not "perfect" records of an individual's environmental and physiological history. Otolith composition appears to be determined by a complex interaction of environmental history, physiology, genetics, and structural constraints. To quote the "old" maxim, "otoliths weren't designed with biologists in mind." Although a few major events, such as migration between marine and fresh

> water might leave an unambiguous record in an otolith, more often the signals we seek are likely to be weak, multivariate, and difficult to interpret. Although "pure" environmental markers may well exist in otoliths, I suspect that otolith composition will ultimately prove of greatest use in reconstructing the physiological, rather than environmental history of an individual. In the end, the promise of vast information gains from analysis of otolith composition is still there and real, but this promise will only be achieved by means of careful well designed and well executed experimental studies."

The failure of this study to apply otolith microchemistry data to further scientific understanding of the life history of humpback chub should not be construed as evidence that this avenue of research does not still have merit, or that it may not one day prove useful in management of this species. The hypothesis that otoliths record environmental history of individuals is most likely correct, but as Thresher and others have pointed out, new, highly precise analytical techniques and complex multivariate analyses and physiological studies will likely be required to extract this signal from the "noise" of other factors also affecting otolith chemistry.

BIBLIOGRAPHY

Several recently published works provide useful overviews of otolith preparation methods {8420, 8421, 8421, 8926}, data extraction and analysis {8418, 8419, 8422, 8423, 8424, 8425}, and general overviews of the state of development of otolith related research tools {8840} to which readers of this report should turn for additional information. As these reviews concur, the recent literature tends to be cautionary and it is becoming more generally recognized that much remains to be learned in this rapidly developing area of fisheries science. It is the consensus of most in the field that otolith studies have great potential for providing much needed detailed insights into aspects of fish life histories that can not be otherwise obtained, or which could be obtained only with great expense and effort. On the other hand, it seems also to be the consensus that the tools of the trade are still very much in the developmental stage, and data must be interpreted with extreme caution. Much of the existing literature has been recently found to have made major errors in interpretation of data, and precision of analytical techniques being widely applied only a few years ago has been demonstrated to be inadequate for most applications (see especially critiques of electron microprobe analysis for elemental composition of otoliths {6151, 8152}. An "old maxim" provided by Thresher {8841} in his overview of the session on Otolith Composition at the 1993 international otolith conference in Hilton Head South Carolina, succinctly conveys the considerable difficulties of applying otolith studies to management problems - "otoliths weren't designed with biologists in mind."

1. Adams, C.E.; Murray, K.R.; Huntingford, F.A. The periodicity of primary increment formation

in the otoliths of Arctic charr *Salvelinus alpinus* (L). J. Fish Biol. 41(4):515-520; 1992.

2. Agnalt, A.-L. Long-term changes in growth and age at maturity of mackerel, *Scomber scombrus* L., from the North Sea. J. Fish Biol. 35 SA:305-312; 1989.

3. Ahrenholz, D.W.; Fitzhugh, G.R.; Rice, J.A.; Nixon, S.W.; Pritchard, W.C. Confidence of otolith ageing through the juvenile stage for Atlantic menhaden, *Brevoortia tyrannus*. Fish. Bull. .U. S. 93:209-216; 1995.

4. Al-Hossaini, M.; Liu, Q.; Pitcher, T.J. Otolith microstructure indicating growth and mortality among plaice, *Pleuronectes platessa* L., post-larval sub-cohorts. J. Fish Biol. 35 SA:81-90; 1989.

5. Al-Hossaini, M.; Pitcher, T.J. The relation between daily rings body growth and environmental factors in plaice *Pleuronectes platessa* L. juvenile otoliths. J. Fish Biol. 33:409-418; 1988.

6. Alegria-Hernandez, V. Study on the age and growth of Bogue (*Boops boops* (L.)) from the central Adriatic Sea. Cybium 13(3):281-288; 1989.

7. Amiel, A.J.; Friedman, G.M.; Miller, D.S. Distribution and nature of incorporation of trace elements in modern aragonitic corals. Sedimentology 20:47-64; 1973.

8. Anderson, J.R.; Morison, A.K.; Ray, D.J. Age and growth of Murray Cod, Maccullochella peelii (Perciformes,Percichthyidae), in the lower Murray-Darling Basin, Australia, from thin-sectioned otoliths. Aust. J. Mar. Freshwat. Res. 43(5):983-1013; 1992.

9. Anderson, J.R.; Morison, A.K.; Ray, D.J. Validation of the use of thin-sectioned otoliths for determining the age and growth of Golden Perch, Macquaria ambigua (Perciformes, Percichthyidae), in the Lower Murray-Darling Basin, Australia. Aust. J. Mar. Freshwat. Res. 43(5):1103-1128; 1992.

10. Arai, N.; Sakamoto, W.; Maeda, K. Analysis of trace elements in otoliths of red sea bream *Pagrus major*. FISH. SCI. 61:43-47; 1995.

11. Arkhipkin, A.I. A comparative analysis of subannual growth zones in squid statoliths and fish otoliths. Biol. Nauki. (Mosc.) 5-16; 1988.

12. Asano, M.; Mugiya, Y. Biochemical and calcium-binding properties of water-soluble proteins isolated from otoliths of the tilapia, Oreochromis niloticus. Comp. Biochem. Physiol. Pt. B 104(1):201; 1993.

13. Bagenal, T.B. The Ageing of Fish. Proceedings of an International Symposium. Old Woking, Surrey, England: Unwin Brothers, Ltd., The Gresham Press; 1974:

14. Bailey, K.M.; Stehr, C.L. The effects of feeding periodicity and ration on the rates of increment formation in otoliths of larval walleye pollock *Theragra chalcogramme* (Pallas). J. Exp. Mar. Biol. Ecol. 122(2):147-162; 1988.

15. Baluk, W.; Radwanski, A. New data on the korytnica basin its organic communities and ecological relationships between species middle miocene holy-cross mountains central Poland. Acta Geol. Pol. 34:1985); 1984.

16. Barkman, R.C.; Bengston, D.A. The record of daily growth in otoliths of Atlantic silversides *Menidia menidia* from field and laboratory. J. Fish Biol. 31:683-696; 1987.

17. Beamish, R.J.; Fournier, D.A. A method for comparing the precision of a set of age determinations. Can. J. Fish. Aquat. Sci. 38:982-983; 1981.

18. Beckman, D.W.; Wilson, C.A. Seasonal timing of opaque zone formation in fish otoliths. Secor, D.H.; Dean, J.M.; Campana, S.E. eds. 27-43; 1995.

19. Beltran, R.R.; Vincent, G. Use of trypsin to extract and examine larval fish otoliths. Cybium 17(1):77-78; 1993.

20. Bengston, B.E.; Larson, A. Vertebral deformities and physiological effects in fourhorn sculpin *Myoxocephalus quadricornis* after long-term exposure to a simulated heavy metal containing

effluent. Aquat. Toxicol. (Amst.) 9:1987); 1986.

21. Bennet, J.T.; Boehlert, G.W.; Turekian, K.K. Confirmation of longevity in *Sebastes diploproa* (Pisces:Scorpaenida) from 210 Pb/226Ra measurements in otoliths. Mar. Biol. 71:209-215; 1982.

22. Berman, M.C.; King, S.B. Stoichiometries of calcium and strontium transport coupled to ATP and acetyl phosphate hydrolysis by skeletal sarcoplasmic reticulum. Biochim. Biophys. Acta 1029:235-240; 1990.

23. Bird, J.L.; Eppler, D.T.; Checkley D, M.J. Comparisons of Herring otoliths using fourier series shape analysis. Can. J. Fish. Aquat. Sci. 43:1228-1234; 1986.

24. Boehlert, G.W.; Kappenman, R.F. Variation of growth and latitude in 2 species of rockfish *Sebastes pinniger* and *Sebastes diploproa* from Northeast Pacific Ocean. Mar. Ecol. Prog. Ser. 3:1981); 1980.

25. Boehlert, G.W.; Yoklavich, M.M.; Chelton, D.B. Time series of growth in the genus Sebastes form the Northeast Pacific Ocean. Fish. Bull. ,U. S. 87(4):791-806; 1989.

26. Bolz, G.R.; Lough, R.G. Growth through the first six months of Atlantic cod *Gadus morhua* and haddock *Melanogrammus aeglefinus* based on daily otolith increments. Fish. Bull. ,U. S. 86:223-236; 1988.

27. Bradford, M.J.; Green, G.H. Growth estimates from otolith increment widths of juvenile chinook salmon (Oncorhynchus tshawytscha) reared in changing environments. J. Fish Biol. 41(5):825-832; 1992.

28. Bronte, C.R.; Hesselberg, R.J.; Shoesmith, J.A.; Hoff, M.H. Discrimination among spawning concentrations of Lake Superior lake herring based on trace element profiles in sagittae. Trans. Amer. Fish Soc. 125:852-859; 1996.

29. Brooks, R.C.; Heidinger, R.C.; Hohler, C.C. Mass-marking otoliths of larval and juvenile

walleyes by immersion in oxytetracycline, calcein, ar calcein blue. N. Amer. J. Fish. Mgmt. 14:143-150; 1994.

30. Brothers, E.B. Methodological approaches to the examination of otoliths in aging studies. Summerfelt, R.C.; Hall, G.E. eds. 1: 5. 319-330; 1987.

31. Brothers, E.B. Otolith marking. Amer. Fish. Soc. Symp. 7:183-202; 1990.

32. Brothers, E.B. Estimation of growth: overview II. Secor, D.H.; Dean, J.M.; Campana, S.E. eds. 79-80; 1995.

33. Brothers, E.B.; Jones, C. Validation of the otolith increment aging technique for striped bass, *Morone saxatilis*, larvae reared under suboptimal feeding conditions. Fish. Bull. ,U. S. 85(2):171-178; 1987.

34. Brzobohaty, R. The lower Miocene otolith fauna of Maigen near Eggenburg lower Austria. No Journal Found ; 1990.

35. Burke, J.S.; Peters, D.S.; Hanson, P.J. Morphological indices and otolith microstructure of Atlantic croaker, Micropogonias undulatus, as indicators of habitat quality along an estuarine pollution gradient. Environ. Biol. Fishes 36(1):25-34; 1993.

36. Butler, J.L. Collection and preservation of material for otolith analysis. Stevenson, D.K.; Campana, S.E. eds. 13-17; 1992.

37. Campana, S.E. Calcium deposition and otolith check ring formation during periods of stress in coho salmon, *Oncorhynchus kisutch*. Comp. Biochem. Physiol. 75:215-220; 1983.

38. Campana, S.E. Otolith microstructure of three larval gadids in the Gulf of Maine Atlantic Ocean with inferences on early life history. Can. J. Zool. 67:1401-1410; 1989.

39. Campana, S.E. How reliable are growth back-calculations based on otoliths? Can. J. Fish. Aquat.

Sci. 47:2219-2227; 1990.

40. Campana, S.E. Measurement and interpretation of the microstructure of fish otoliths. Stevenson, D.K.; Campana, S.E. eds. 59-71; 1992.

41. Campana, S.E.; Annand, M.C.; McMillan, J.I. Graphical and statistical methods for determining the consistency of age determinations. Trans. Amer. Fish Soc. 124:131-138; 1994.

42. Campana, S.E.; Casselman, J.M. Stock discrimination using otolith shape analysis. Can. J. Fish. Aquat. Sci. 50:1062-1083; 1993.

43. Campana, S.E.; Gagne, J.A. Cod stock discrimination using ICPMS elemental assays of otoliths. Secor, D.H.; Dean, J.M.; Campana, S.E. eds. 671-691; 1995.

44. Campana, S.E.; Gagne, J.A.; McLaren, J.W. Elemental fingerprinting of fish otoliths using ID-ICPMS. Mar. Ecol. Prog. Ser. 122:115-120; 1995.

45. Campana, S.E.; Hurley, P.C.F. An age and temperature-mediated growth model for cod *Gadus morhua* and haddock *Melanogrammus aeglefinus* larvae in the Gulf OF Maine USA Canada. Can. J. Fish. Aquat. Sci. 46:603-613; 1989.

46. Campana, S.E.; Jones, C.M. Analysis of otolith microstructure data. Stevenson, D.K.; Campana, S.E. eds. 73-100; 1992.

47. Campana, S.E.; Moksness, E. Accuracy and precision of age and hatch date estimates from otolith microstructure examination. Ices. J. Sci. 48(3):303-316; 1991.

48. Campana, S.E.; Neilson, J.A. Microstructure of fish otoliths. Can. J. Fish. Aquat. Sci. 42:1014-1032; 1985.

49. Campana, S.E.; Oxenford, H.A.; Smith, J.N. Radiochemical determination of longevity in flyingfish *Hirundichthys affinis* using Th-228/Ra-228. Mar. Ecol. Prog. Ser. 100:211-219; 1993.

50. Campana, S.E.; Zwanenburg, K.C.T.; Smith, J.N. 210 PB/226 Ra determination of longevity in redfish. Can. J. Fish. Aquat. Sci. 47:163-165; 1990.

51. Casselman, J.M. Growth and relative size of calcified structures of fish. Trans. Amer. Fish Soc. ; 1991.

52. Castonguay, M.; Simard, P.; Gagnon, P. Usefulness of fourier analysis of otolith shape for Atlantic mackerel (*Scomber scombrus*) stock discrimination. Can. J. Fish. Aquat. Sci. 48(2):296-302; 1991.

53. Chauvelon, P.; Bach, P. Modelling the otolith shape as an ellipse - an attempt for back-calculation purposes. Ices. J. Sci. 50(2):121-128; 1993.

54. Childress, J.J.; Taylor, S.M.; Cailliet, G.M.; Price, M.H. Patterns of growth energy utilization and reproduction in some meso pelagic and bathy pelagic fishes off Southern California USA. Mar. Biol. 61:1981); 1980.

55. Chisnall, B.L.; Kalish, J.M. Age validation and movement of freshwater eels (*Anguilla dieffenbachii* and *A. australis*) in a New Zealand pastoral stream. N. Z. J. Mar. Freshw. Res. 27:333-338; 1993.

56. Chivas, A.R.; De Deckker, P.; Shelley, J.M.G. Strontium content of ostracods indicates lacustrine paleosalinity. Nature 316:251-253; 1985.

57. Cicilykutty, A.K.; Balasubramanian, N.K.; John, P.A. The influence of physical conditions salt content of the flesh of fish on the intensity of infestation by adult mite *Suidasia medanensis*. Acarologia. (Paris) 22:1982); 1981.

58. Coggan, R.; Skora, K.; Murray, A.; White, M. A comparison between age determination of the antarctic fish *Notothenia gibberifrons* Lonnberg using scales and otoliths. Cybium 14(1):43-55; 1990.

59. Coote, G.E.; Gauldie, R.W.; West, I.F. Application of a nuclear microprobe to the study of fish otoliths and scales. Nucl. Instrum. Meth. 54:144-150; 1991.

60. Crawford, S.; Coleman, W.S.; Porak, W.F. Time of annulus formation in otoliths of Florida largemouth bass. N. Amer. J. Fish. Mgmt. 9:231-233; 1989.

61. Dawson, W.A. Otolith measurement as a method of identifying factors affecting 1st-year growth and stock separation of mackerel (*Scomber scombrus* L). J. Conseil. 47(3):303-317; 1991.

62. Degens, E.T.; Deuser, W.G.; Haedrich, R.L. Molecular structure and composition of fish otoliths. Mar. Biol. 2:105-113; 1969.

63. Devereux, I. Temperature measurements from oxygen isotope ratios of fish otoliths. Science 155:1684-1685; 1967.

64. Domanevskii, L.N.; Galaktionova, A.I. Morphoecological characteristics of the scad *Trachurus trecae* from the Eastern Central Atlantic. Vopr. Ikhtiol. 29:209-216; 1989.

65. Douabul, A.A.Z.; Al-Saad, H.T.; Al-Obaidy, S.Z.; Al-Rekabi, H.N. Residues of organochlorine pesticides in fish from the Arabian Gulf. Water,Air,and Soil Pollution 35:187-194; 1987.

66. Dunkelberger, D.G.; Dean, J.M.; Watabe, N. The ultrastructure of the otolith membrane and otolith in the juvenile mummichog, *Fundulus heteroclitus*. J. Morphol. 163:367-377; 1980.

67. Eckert, R.; Randall, D. Animal physiology. San Francisco: W.H. Freeman; 1978:

68. Eckmann, R.; Rey, P. Daily increments on the otoliths of larval and juvenile *Coregonus* spp. and their modification by environmental factors. Hydrobiologia 148(2):137-144; 1987.

69. Edmonds, J.S.; Caputi, N.; Moran, M.J.; Fletcher, W.J.; Morita, M. Population discrimination by variation in concentrations of minor and trace elements in sagittae of two western Australian teleosts. Secor, D.H.; Dean, J.M.; Campana, S.E. eds. 655-670; 1995.

70. Edmonds, J.S.; Caputi, N.; Morita, M. Stock discrimination by trace-element analysis of otoliths of orange roughy (*Hoplostethus atlanticus*), a deep-water marine teleost. Aust. J. Mar. Freshwat. Res. 42(2):383-398; 1991.

71. Edmonds, J.S.; Lenanton, R.C.J.; Caputi, N.; Morita, M. Trace elements in the otoliths of yellow-eye mullet (*Aldrichetta forsteri*) as an aid to stock identification. Fish Res. 13(1):39-52; 1992.

72. Edmonds, J.S.; Moran, M.J.; Caputi, N.; Morita, M. Trace element analysis of fish sagittae as an aid to stock identification pink snapper *Chrysophrys auratus* in Western Australian waters. Can. J. Fish. Aquat. Sci. 46:50-54; 1989.

73. Fange, R. Exogenous otoliths of Elasmobranchs. J. Mar. Biol. Assoc. U. K. 62:225-226; 1982.

74. Fenton, G.E.; Ritz, D.A.; Short, S.A. $^{210}Pb/^{226}Ra$ disequilibrium in otoliths of blue grenadier, *Macruronus novaez* Chanidae; problems associated with radiometric ageing. Australian Journal of Marine and Freshwater Research 41(4):467-473; 1990.

75. Fenton, G.E.; Short, S.A. Fish age validation by radiometric analysis of otoliths. Aust. J. Mar. Freshwat. Res. 43(5):913-922; 1992.

76. Fenton, G.E.; Short, S.A. Radiometric analysis of blue grenadier, *Macruronus novaezelandiae*, otolith cores. Fish. Bull. ,U. S. 93:391-396; 1995.

77. Fine, M.L.; Horn, M.H.; COX, B. *Acanthonus armatus* a deep-sea Teleost fish with a minute brain and large ears. Proc. R. Soc. Lond. B. Biol. Sci. 230:257-265; 1987.

78. Fitch, J.E. Additional fish remains, mostly otoliths, from a Pleistocene deposit at Playa del Rey, California. Contributions in Science,Natural History Museum,Los Angeles County,California 119:1-16; 1966.

79. Fitch, J.E. The marine fish fauna, based primarily on otoliths, of a lower Pleistocene deposit at

San Pedro, California (LACMIP 332, San Pedro Sand). Contributions in Science,Natural History Museum,Los Angeles County,California 128:1-23; 1967.

80. Fitch, J.E. Otoliths and other fish remains from the Timms Point silt (Early Pleistocene) at San Pedro, California. Contributions in Science,Natural History Museum,Los Angeles County,California 146:1-29; 1968.

81. Fletcher, W.J. A test of the relationship between otolith weight and age for the *Pilchard sardinops neopilchardus*. Can. J. Fish. Aquat. Sci. 48(1):35-38; 1991.

82. Fortier, L.; Gagne, J.A. Larval herring (*Clupea harengus*) dispersion, growth, and survival in the St. Lawrence estuary - Match mismatch or membership vagrancy. Can. J. Fish. Aquat. Sci. 47(10):1898-1912; 1990.

83. Fowler, A.J. Validation of annual growth increments in the otoliths of a small, tropical coral reef fish. Mar. Ecol. Prog. Ser. 64(1-2):25-38; 1990.

84. Fowler, A.J.; Campana, S.E.; Jones, C.M.; Thorrold, S.R. Experimental assessment of the effect of temperature and salinity on elemental composition of otoliths using laser ablation ICPMS. Can. J. Fish. Aquat. Sci. 52:1431-1441; 1995.

85. Francis, M.P.; Williams, M.W.; Pryce, A.C.; Pollard, S.; Scott, S.G. Uncoupling of otolith and somatic growth in Pagrus auratus (Sparidae). Fishery Bulletin 91:159-164; 1993.

86. Francis, R.I.C.C. Otolith radius is a poor predictor of age in adult snapper (Pagrus auratus). Aust. J. Mar. Freshwat. Res. 43(5):1199-1202; 1992.

87. Fritz, P.; Poplawski, S. ^{18}O and ^{13}C in the shells of freshwater molluscs and their environments. Earth and Planetary Science Letters 24:91-98; 1974.

88. Fuiman, L.A.; Hoff, G.R. Natural variation in elemental composition of sagittae from red drum. J. Fish Biol. 47:940-955; 1995.

89. Gaemers, P.A.M.; Vorren, T.O. Otolith stratigraphy of late Weichselian and Holocene sediments of Malangsdjupet off Northern Norway. Nor. Geol. Tidsskr. 65:1986); 1985.

90. Gallahar, N.K.; Kingsfork, M.J. Patterns of increment width and strontium - calcium rates in otoliths of juvenile rock blackfish, Girella elevata. J. Fish Biol. 41(5):749-764; 1992.

91. Gauldie, R.W. Vaterite otoliths from chinook salmon (*Oncorhynchus tshawytscha*). New Zealand Journal of Marine and Freshwater Research 20:209-217; 1986.

92. Gauldie, R.W. The fine structure of check rings in the otolith of the New Zealand orange roughy (*Hoplostethus atlanticus*). New Zealand Journal of Marine and Freshwater Research 21:267-274; 1987. (Abstract)

93. Gauldie, R.W. Similarities in fine structure of annual, and non-annual, check rings in the otolith of the New Zealand snapper (*Chrysophrys auratus*). N. Z. J. Mar. Freshw. Res. 20:209-217; 1988.

94. Gauldie, R.W. Form, function and time-keeping properties of otoliths. Comp. Biochem. Physiol. 91:395-402; 1988. (Abstract)

95. Gauldie, R.W. A measure of metabolism in fish otoliths. Comp. Biochem. Physiol. Pt. A 97(4):475-480; 1990.

96. Gauldie, R.W. Vaterite otoliths from the opah, *Lampris immaculatus*, and two species of sunfish, *Mola mola* and *M. ramsayi*. Acta Zoologica 71(4):193-200; 1990.

97. Gauldie, R.W. How often is the von Bertalanffy-type length-at-age curve in fishes related to weight change artefacts interpreted as age rings in otoliths? Comp. Biochem. Physiol. Pt. A 96(4):451-458; 1990.

98. Gauldie, R.W. Phase differences between check ring locations in the orange roughy otolith (*Hoplostethus atlanticus*). Can. J. Fish. Aquat. Sci. 47(4):760-765; 1990.

99. Gauldie, R.W. The morphology and periodic structures of the otolith of the chinook salmon (*Oncorhynchus tshawytscha*), and temperature -dependent variation in otolith microscopic growth increment width. Acta Zoologica 72(3):159-179; 1991.

100. Gauldie, R.W. Age and growth of orange roughy *Hoplostethus atlanticus*. Reconstruction of the growth history of the orange roughy otolith from microincrements and checks. J. Appl. Ichthyol. 1992. (In Press)

101. Gauldie, R.W. Continuous and discontinuous growth in the otolith of *Macruronus novaezelandiae* (Merlucciidae: Teleostei). J. Morphol. 216:271-294; 1993.

102. Gauldie, R.W. Biological history and age estimation from the zones, checks, and microincrements of the otolith of the alfonsin, *Beryx splendens* (Berycidae). Cybium 19:107-129; 1995.

103. Gauldie, R.W.; Coote, G.; Mulligan, K.P.; West, I.F.; Merrett, N.R. Otoliths of deep water fishes - Structure, chemistry and chemically-coded life histories. Comp. Biochem. Physiol. Pt. A 100(1):1-32; 1991.

104. Gauldie, R.W.; Coote, G.; West, I.F. The otoliths of senescent Kahawai, *Arripis trutta* (Arripidae). Cybium 17(1):25-37; 1993.

105. Gauldie, R.W.; Coote, G.C.; Mulligan, K.P.; West, I.F. A chemical probe of the microstructural organization of fish otoliths. Comp. Biochem. Physiol. Pt. A 102(3):533-546; 1992.

106. Gauldie, R.W.; Davies, N.M.; Coote, G.; Vickridge, I. The relationship between organic material and check rings in fish otoliths. Comp. Biochem. Physiol. Pt. A 97(4):461-474; 1990.

107. Gauldie, R.W.; Davies, N.M.; West, I.F. Variation in length-at-age over time and space of the orange roughy *Hoplostethus atlanticus*. J. Appl. Ichthyol. 1992. (In Press)

108. Gauldie, R.W.; Fournier, D.A.; Dunlop, D.E. Atomic emission and protom microprobe studies

on the ion content of otoliths of chinook salmon aimed at recovering the temperature life history of individuals. Comp. Biochem. Physiol. Pt. A 84:607-615; 1986.

109. Gauldie, R.W.; Fournier, D.A.; Dunlop, D.E. The effect of surface sculpturing on the interpretation of opaque and hyaline zones in the orange roughy otolith. J. Appl. Ichthyol. 4:140-146; 1988.

110. Gauldie, R.W.; Graynoth, E.J.; Illingworth, J. The relationship of the iron content of some fish otoliths to temperature. Comp. Biochem. Physiol. Pt. A 66:19-24; 1980.

111. Gauldie, R.W.; Nathan, A. Iron content of the otoliths of tarakihi (Teleostei: Cheilodactylidae). New Zealand Journal of Marine and Freshwater Research 11:179-191; 1977.

112. Gauldie, R.W.; Nelson, D.G.A. Aragonite twinning and neuroprotein secretion are the cause of daily growth rings in fish otoliths. Comp. Biochem. Physiol. 90:501-510; 1988.

113. Gauldie, R.W.; Nelson, D.G.A. Mechanisms of otolith growth in fishes. Comp. Biochem. Physiol. in press: 1990.

114. Gauldie, R.W.; Radtke, R.L. Microincrementation: facultative and obligatory percipitation of otolith crystal. Comp. Biochem. Physiol. 97(A):137-144; 1990.

115. Gauldie, R.W.; Raina, G.; Nelson, D.G.A. Atomic force and transmission eletron microscopy of the mineral and matrix structure of fish otolith crystals. In Press 1992. (In Press)

116. Gauldie, R.W.; West, I.F. Age determination of fish using 210 Pb/226 Ra disequilibria. Mar. Biol. 1991. (In Press)

117. Gauldie, R.W.; West, I.F.; Coote, G. Evaluating age estimation of *Hoplostethus atlanticus* by comparing patterns of checks and microscopic growth increments with annual cycles in the strontium composition of the otolith. Bull. Mar. Sci. 1992. (In Press)

118. Gauldie, R.W.; West, I.F.; Coote, G.E. Evaluating otolith age estimates for *Hoplostethus atlanticus* by comparing patterns of checks, cycles in microincrement width, and cycles in strontium and calcium composition. Bull. Mar. Sci. 56:76-102; 1995.

119. Gauldie, R.W.; West, I.F.; Davies, N.M. K-selection characteristics of orange roughy (*Hoplostethus atlanticus*) stocks in New Zealand waters. J. Appl. Ichthyol. 5:127-140; 1989.

120. Gauldie, R.W.; Xhie, J. Atomic force microscopy of the morphology of the matrix and mineral components of the otolith of *Hyperoglyphe antarctica*. J. Morphol. 223:203-214; 1995.

121. Geffen, A.J. Validation of otolith increment deposition rate. Stevenson, D.K.; Campana, S.E. eds. 101-113; 1992.

122. Geffen, J.A. Methods of validating daily increment deposition in otoliths of larval fish. Summerfelt, R.C.; Hall, G.E. eds. 1: 4. 223-240; 1987.

123. Gjosaeter, H.; Loeng, H. Growth of the Barents Sea Capelin *Mallotus villosus* in relation to climate. Environ. Biol. Fishes 20:293-300; 1987.

124. Gjosaeter, J.; Lonnhaug, K. Back-calculation of growth from broken cod otoliths. Fish. Res. 9(3):283-286; 1990.

125. Grady, J.R.; Johnson, A.G.; Sanders, M. Heavy metal content in otoliths of king mackerel (*Scomberomorus cavalla*) in relation to body length and age. Contrib. Mar. Sci. 31:17-24; 1990.

126. Graham, R.J.; Orth, D.J. Otolith aging of young-of-year smallmouth bass. Summerfelt, R.C.; Hall, G.E. eds. 483-492; 1987.

127. Graynoth, E. Growth of landlocked sockeye salmon *Oncorhynchus nerka* in New Zealand. New Zealand Journal of Marine and Freshwater Research 21:15-30; 1987.

128. Green, G.H.; Neilson, J.D.; Bradford, M. Effects of pH on the early development and growth

and otolith microstructure of chinook salmon, *Oncorhynchus tshawytscha*. Can. J. Zool. 63:22-27; 1985.

129. Greenberg, L.A.; Brothers, E.B. Intrastream variation in growth rates and time of first otolith increment formation for young of the year *Etheostoma simoterum* (Cope) (Perciformes: Percidae). J. Fish Biol. 38(2):237-242; 1991.

130. Greenberg, L.A.; Brothers, E.B. Intrastream variation in growth rates and time of first otolith increment formation for young of the year *Etheostoma simoterum* (Cope) (Perciformes: Percidae). J. Fish Biol. 38(2):237-242; 1991.

131. Gunn, J.S.; Harrowfield, J.R.; Proctor, C.H.; Thresher, R.E. Electron probe microanalysis of fish otoliths - evaluation of techniques for studying age and stock discrimination. J. Exp. Mar. Biol. Ecol. 158:1-36; 1992.

132. Hagen, P.; Munk, K.; Van Alen, B.; White, B. Thermal mark technology for inseason fisheries management: A case study. ALASKA FISH. RES. BULL. 2:143-155; 1995.

133. Hallam, A.; Price, N.B. Environmental and biochemical control of strontium in shells of *Cardium edule*. Geochim. Cosmochim. Acta 32:319-328; 1968.

134. Hare, J.A.; Cowen, R.K. Effect of age, growth rate, and ontogeny on the otolith size -- fish size relationship in bluefish, *Pomatomus saltatrix*, and the implications for back-calculation of size in early life history stages. Can. J. Fish. Aquat. Sci. 52:1909-1922; 1995.

135. Haro, A.J.; Krueger, W.H. Pigmentation, otolith rings, and upstream migration of juvenile American eels (*Anguilla rostrata*) in a coastal Rhode Island streams. Can. J. Zool. 69(3):812-814; 1991.

136. Hartvich, P.; Kubecka, J. Evaluation of fish growth by the method of increment differences. Zivocisna Vyroba 34(10):917-924; 1989.

137. Hendrick, E.S. X-ray fluorenscence analysis of the elemental composition of otoliths from striped bass (*Morone saxatilis*), as an environmental marker useful in stock discriminationand pollution studies. 1978:

138. Hendricks, M.L.; Bender, T.R.J.; Mudrak, V.A. Multiple marking of American shad otoliths with tetracycline antibiotics. N. Amer. J. Fish. Mgmt. 11(2):212-219; 1991.

139. Hendricks, M.L.; Torsello, D.L.; Backman, T.W.H. Use of otolith microstricture to distinguish wild from hatchery-reared American shad in the Susquehanna River. N. Amer. J. Fish. Mgmt. 14:151-161; 1994.

140. Hill, K.T.; Cailliet, G.M.; Radtke, R.L. A comparative analysis of growth zones in four calcified structures of Pacific blue marlin, *Makaira nigricans*. Fish. Bull. ,U. S. 87(4):829-844; 1989.

141. Hill, K.T.; Radtke, R.L. Gerontological studies of the damselfish *Dascullus albisella*. Bull. Mar. Sci. 42:424-434; 1988.

142. Hoff, G.R.; Fuiman, L.A. Morphometry and composition of red drum otoliths: changes associated with temperature, somatic growth rate, and age. Comp. Biochem. Physiol. 106A:209-219; 1993.

143. Hoff, G.R.; Fuiman, L.A. Environmentally induced variation in elemental composition of red drum (*Sciaenops ocellatus*) otoliths. Bull. Mar. Sci. 56:578-591; 1995.

144. Hogler, S.R.; Belanger, S.E. The use of various fish aging methodologies. Ohio Journal of Science 82:4; 1982.

145. Hovenkamp, F. Growth differences in larval plaice *Pleuronectes platessa* in the Southern Bight of the North Sea as indicated by otolith increments and RNA/DNA ratios. Mar. Ecol. Prog. Ser. 58(3):205-215; 1990.

146. Hovenkamp, F.; Witte, J.I. Growth, otolith growth and RNA/DNA ratios of larval plaice

Pleuronectes platessa in the North Sea 1987 to 1989. Mar. Ecol. Prog. Ser. 70(2):105-116; 1991.

147. Hovenkamp, F.; Witte, J.I. Growth, otolith growth and RNA/DNA ratios for larval plaice *Pleuronectes platessa* in the North Sea 1987 to 1989. Mar. Ecol. Prog. Ser. 70:105-116; 1991.

148. Hyndes, G.A.; Loneragan, N.R.; Potter, I.C. Influence of sectioning otoliths on marginal increment trends and age and growth estimates for the flathead *Platycephalus speculator*. Fish. Bull. ,U. S. 90(2):276-284; 1992.

149. Iacumin, P.; Bianucci, G.; Longinelli, A. Oxygen and carbon isotopic composition of fish otoliths. Mar. Biol. 113(4):537-542; 1992.

150. Ichii, T.; Mugiya, Y. Compatative aspects of calcium dynamics in calcified tissues in the goldfish *Carassius auratus*. Bull. JPN. Soc. Sci. Fish 49:1039-1044; 1983.

151. Isely, J.J.; Noble, R.L. Use of daily otolith rings to interpret development of length distributions of young largemouth bass. Summerfelt, R.C.; Hall, G.E. eds. 475-482; 1987.

152. Ishii, T.; Inoue, K.; Takayama, M.; Ito, S. Distribution of melanocytes and chemical analysis of melanin in labyrinth. Pract. Otol. Kyoto. 8); 1986.

153. Jearld, A., Jr. Age determination. Nielsen, L.A.; Johnson, D.L.; Lampton, S.S. eds. 301-324; 1983.

154. Jenkins, G.P.; Davis, T.L.O. Age, growth rate, and growth trajectory determined from otolith microstructure of southern bluefin tuna *Thunnus maccoyii* larvae. Mar. Ecol. Prog. Ser. 63(1):93-104; 1990.

155. Jones, C.M. Development and application of the otolith increment technique. Stevenson, D.K.; Campana, S.E. eds. 1-12; 1992.

156. Jones, C.M. Session IV. Overview II. Secor, D.H.; Dean, J.M.; Campana, S.E. eds. 633-636;

1995.

157. Kalish, J.M. Otolith microchemistry: validation of the effects of physiology, age and environment on otolith composition. J. Exp. Mar. Biol. Ecol. 132(3):151-178; 1989.

158. Kalish, J.M. Use of otolith microchemisty to distinguish the progeny of sympatric anadramous and non-anadromous salmonids. Fish. Bull. ,U. S. 88:657-666; 1990.

159. Kalish, J.M. C-13 and O-18 isotopic disequilibria in fish otoliths: metabolic and kinetic effects. Mar. Ecol. Prog. Ser. 75(2-3):191-204; 1991.

160. Kalish, J.M. Determinants of otolith chemistry - Seasonal variation in the composition of blood plasma, endolymph and otoliths of bearded rock cod *Pseudophycis barbatus*. Mar. Ecol. Prog. Ser. 74:137-159; 1991.

161. Kalish, J.M. Oxygen and carbon stable isotopes in the otoliths of wild and laboratory-reared Australian salmon (*Arripis trutta*). Mar. Biol. 110(1):37-48; 1991.

162. Kalish, J.M. Super(13)C and super(18)O isotopic disequilibria in fish otoliths: Metabolic and kinetic effects. Mar. Ecol. Prog. Ser. 75:191-203; 1991.

163. Kalish, J.M. Formation of a stress-induced chemical check in fish otoliths. J. Exp. Mar. Biol. Ecol. 162(2):265-278; 1992.

164. Kalish, J.M. Fish otolith chemistry. Science 260(5106):279; 1993.

165. Kalish, J.M. Pre- and post-bomb radiocarbon in fish otoliths. Earth and Planetary Science Letters 114:549-554; 1993.

166. Kalish, J.M. Application of the bomb radiocarbon chronometer to the validation of redfish *Centroberyx affinis* age. Can. J. Fish. Aquat. Sci. 52:1399-1405; 1995.

167. Kalish, J.M.; Beamish, R.J.; Brothers, E.B.; Casselman, J.M.; Francis, R.I.C.C.; Mosegaard, H.; Panfili, J.; Prince, E.D.; Thresher, R.E.; Wilson, C.A.; Wright, P.J. Glossary for otolith studies. Secor, D.H.; Dean, J.M.; Campana, S.E. eds. 723-729; 1995.

168. Karakiri, M.; Berghahn, R.; Von Westernhagen, H. Growth differences in O-group plaice *Pleuronectes platessa* as revealed by otolith microstructure analysis. Mar. Ecol. Prog. Ser. 55(1):15-22; 1989.

169. Karakiri, M.; Von Westernhagen, H. Apparatus for grinding otoliths of larval and juvenile fish for microstructure analysis. Mar. Ecol. Prog. Ser. 49(1-2):195-198; 1988.

170. Keith, M.L.; Anderson, G.M.; Eichler, R. Carbon and oxygen isotopic composition of mollusk shells from marine and fresh-water environments. Geochim. Cosmochim. Acta 28:1757-1786; 1964.

171. Khan, K.M.; Drescher, D.G. Proteins of the gelatinous layer of the trout saccular otolithic membrane. Hear. Res. 43(2-3):149-158; 1990.

172. Kieser, R.; Mulligan, T.J. X-ray flourescence spectroscopy as a tool for fish stock discrimination. Advances in X-ray Analysis 19:487-495; 1976.

173. Kimura, D.K.; Kastelle, C.R. Perspectives on the relationship between otolith growth and the conversion of isotope activity ratios to fish ages. Can. J. Fish. Aquat. Sci. 52:2296-2303; 1995.

174. Kinsman, D.F.; Holland, H.D. The coprecipitations of cations of $CaCO_3$, IV. The coprecipitation of Sr^{2+} with aragonite between 16C and 96C. Geochim. Cosmochim. Acta 33:1-17; 1969.

175. Klink, A.; Eckman, R. Limits for the detection of daily otolith increments in whitefish (*Coregonus lavaretus* L) larvae. Hydrobiologia 231(2):99-106; 1992.

176. Kruse, G.H.; Dalley, E.L. Length changes in capelin, *Mallotus villosus* (Muller), larvae due to preservation in formalin and anhydrous alcohol. J. Fish Biol. 36(4):619-622; 1990.

177. Labeelund, J.H.; Jensen, A.J. Otoliths as natural tags in the systematics of Salmonids. Environ. Biol. Fishes 36(4):389-393; 1993.

178. Lagardère, F.; Chaumillon, G.; Amara, R.; Heineman, G.; Lago, J.M. Examination of otolith morphology and microstructure using Laser Scanning Microscopy. Secor, D.H.; Dean, J.M.; Campana, S.E. eds. 7-26; 1995.

179. Lecomtefiniger, R. Growth history and age at recruitment of European glass eels (Anguilla anguilla) as revealed by otolith microstructure. Biol. 114(2):205-210; 1992.

180. Lecomtefiniger, R. The crystalline ultrastructure of otoliths of the eel (*A. anguilla* L 1758). J. Fish Biol. 40(2):181-190; 1992.

181. Lecomtefiniger, R.; Yahyaoui, A. Otolith microstructure analysis in the knowledge of the early life history of the european eel, *Anguilla anguilla*. Int. Revue ges. Hydrobiol. 5(6):861-862; 1990.

182. Limburg, K.E. Otolith strontium traces environmental history of subyearling American shad *Alosa sapidissima*. Mar. Ecol. Prog. Ser. 119:25-35; 1995.

183. Limburg, K.E. Growth and migration of 0-year American shad (*Alosa sapidissima*) in the Hudson River estuary: otolith microstructural analysis. Can. J. Fish. Aquat. Sci. 53:220-238; 1996.

184. Linkowski, T.B.; Radtke, R.L.; Lenz, P.H. Otolith microstructure, age and growth of two species of *Ceratoscopelus* (Osteichthyes: Myctophidae) from the eastern North Atlantic. J. Exp. Mar. Biol. Ecol. 1991. (In Press)

185. Lombarte, A. Changes in otolith area - Sensory area ratio with body size and depth. Environ. Biol. Fishes 33(4):405-418; 1992.

186. Lombarte, A.; Lleonart, J. Otolith size changes related with body growth, habitat depth and temperature. Environ. Biol. Fishes 37(3):297-306; 1993.

187. Lorens, R.B. Sr, Cd, Mn, and Co distribution coefficients in calcite as a function of calcite precipitation rate. Geochim. Cosmochim. Acta 45:553-561; 1981.

188. Loubens, G.; Sarmiento, J. Observations about the fishes in the Bolivian zone of Lake Titicaca II *Orestias agassii* (Pisces:Cyprinodontidae). Rev. Hydrobiol. Trop. 18:159-170; 1985.

189. Love, R.M. The chemical biology of fishes. Academic Press; 1980:377pp

190. Maceina, M.J.; Murphy, B.R. Differences in otolith morphology among the two subspecies of largemouth bass and their F1 hybrid. Trans. Amer. Fish Soc. 118(5):573-575; 1989.

191. Maillet, G.L.; Checkley, D.M. Effects of starvation on the frequency of formation and width of growth increments in Sagittae of laboratory-reared Atlantic Menhaden *Brevoortia tyrannus* larvae. Fish. Bull. ,U. S. 88(1):155-166; 1990.

192. Maillet, G.L.; Checkley, D.M. Storm-related variation in the growth rate of otoliths of larval Atlantic Menhaden *Brevoortia tyrannus* - A time series analysis of biological and physical variables and implications for larva growth and mortality. Mar. Ecol. Prog. Ser. 79(1-2):1-16; 1991.

193. Maisey, J.G. Notes on the structure and phylogeny of vertebrate otoliths. Copeia 1987(2):495-498; 1987.

194. Maisse, G.; Bagliniere, J.L. Limits of method of discrimination between seawater and freshwater origins of trout (*Salmo trutta* L.) using the scale strontium level. Bull. Fr. Peche Piscic. (316):24-27; 1990.

195. Malan, A.; Wilson, T.L.; Reeves, R.B. Intracellular pH in cold-blooded vertabrates as a function of body temperature. Resp. Physiol. 28:29-47; 1976.

196. Mann, S. Crystallochemical strategies in biomineralization. Mann, S.; Webb, J.; Williams, R.J.P. eds. 35-62; 1989.

197. Mann, S.; Parker, S.B.; Ross, M.D.; Skarnulis, A.J.; Williams, R.J.P. The ultrastructure of the calcium carbonate balance organs of the inner ear an ultra high resolution electron microscopy study. Proc. R. Soc. Lond. B. Biol. Sci. 218:415-424; 1983.

198. Matsui, S.; Tomishige, S.-I.; Tsukahara, H. Ecological studies on the engraulid fish *Coilia nasus* I. preliminary report on the ecology of the ascending population. Sci. Bull. Fac. Agric. Kyushu. Univ. 40:221-228; 1986.

199. Matsumiya, Y.; Masumoto, H.; Tanaka, M. Ecology of ascending larval and early juvenile Japanese sea bass *Lateolabrax japonicus* in the Chikugo Estuary Japan. Bull. JPN. Soc. Sci. Fish 51:1986); 1985.

200. May, H.M.A.; Jenkins, G.P. Patterns of settlement and growth of juvenile flounder *Rhombosolea tapirina* determined from otolith microstructure. Mar. Ecol. Prog. Ser. 79(3):203-214; 1992.

201. McCarthy, M.S. Vaterite as the crystalline structure of otoliths of the catostomid fish *Xyrauchen texanus* (Abbott). Unpublished Paper 1-2; 1986.

202. McCarthy, M.S.; Minckley, W.L. Age estimation for razorback sucker (Pisces: Catostomidae) from Lake Mohave, Arizona and Nevada. J. Ariz. Nev. Acad. Sci. 21:87-97; 1987.

203. McConnaughey, T. ^{13}C and ^{18}C isotopic disequilibrium in biological carbonates: I. Patterns. Geochim. Cosmochim. Acta 53:151-162; 1989.

204. McConnaughey, T. ^{13}C and ^{18}O isotopic disequilibrium in biological carbonates: II. *In vitro* simulation of kinetic isotope effects. Geochim. Cosmochim. Acta 53:163-171; 1989.

205. McFarlane, G.A.; Beamish, R.J. Effect of an external tag on growth of sablefish (*Anoplopoma fimbria*), and consequences to mortality and age at maturity. Can. J. Fish. Aquat. Sci. 47(8):1551-1557; 1990.

206. Medland, T.E.; Beamish, F.W.H. Lamprey statolith banding patterns in response to temperature, photoperiod, and ontogeny. Trans. Amer. Fish Soc. 120(2):255-260; 1991.

207. Metcalfe, N.B.; Wright, P.J.; Thorpe, J.E. Relationships between social status, otolith size at 1st feeding and subsequent growth in Atlantic salmon (*Salmo salar*). J. Anim. Ecol. 61(3):585-590; 1992.

208. Meunier, F.J.; Pascal, M. Some compatative data on the cyclical growth of skeletal tissues in Osteichthyans. Bull. Soc. Zool. Fr. 105:337-342; 1980.

209. Meyerrochow, V.B.; Cook, I.; Hendy, C.H. How to obtain clues from the otoliths of an adult fish about the aquatic environment it has been in as a larvae. Comp. Biochem. Physiol. Pt. A 103(2):333-336; 1992.

210. Milicich, M.J.; Choat, J.H. Do otoliths record changes in somatic growth rate - conflicting evidence from a laboratory and field study of a temperate reef fish, Parika scaber. Aust. J. Mar. Freshwat. Res. 43(5):1203-1214; 1992.

211. Mills, C.A. The life history of the minnow *Phoxinus phoxinus L.* in a productive stream. Freshw. Biol. 17:53-68; 1987.

212. Moksness, E.; Rukan, K.; Ystanes, L.; Folkvord, A.; Johannessen, A. Comparison of somatic and otolith growth in North Sea herring (*Clupea harengus* L.) larvae: evaluation of growth dynamics in mesocosms. Secor, D.H.; Dean, J.M.; Campana, S.E. eds. 119-134; 1995.

213. Moksness, E.; Wespestad, V. Ageing and back-calculating growth rates of Pacific herring, *Clupa pallasii*, larvae by reading daily otolith increments. Fish. Bull. ,U. S. 87(3):509-514; 1989.

214. Molony, B.W.; Choat, J.H. Otolith increment widths and somatic growth rate - The presence of a time- lag. J. Fish Biol. 37(4):541-552; 1990.

215. Morales-Nin, B. Chemical composition of the otoliths of the sea bass *Dicentrarchus labrax*

(Pisces:Serranidae). Cybium 10:115-120; 1986.

216. Morales-Nin, B.; Fortuno, J.M. Mercury body burden and otolith characteristics of bluefin tuna from the North West Mediterranean (Balearic Sea). Scientia Marina 54(3):277-285; 1990.

217. Morales-Nin, B.; Gutierrez, E.; Massuti, S. Patterns of primary growth increments in otoliths of *Sparus aurata* larvae in relation to water temperature and food consumption. SCI. MAR. (BARC.) 59:57-64; 1995.

218. Morales-Nin, B.Y.O. Structure and composition of otoliths of cape hake *Merluccius capensis*. S. Afr. J. Mar. Sci. 3-10; 1986.

219. Morkert, S.B.; Bergstedt, R.A. Shrinkage of sea lamprey larvae preserved in formalin. N. Amer. J. Fish. Mgmt. 10(4):484-486; 1990.

220. Morris, M.R.; Ryan, M.J. Age at sexual maturity of male *Xiphophorus nigrensis* in nature. Copeia 1990(3):747-750; 1990.

221. Morse, J.W.; Mackenzie, F.T. Geochemistry of sedimentary carbonates. Elsevier. 1990:

222. Mosegaard, H.; Svedang, H.; Taberman, K. Uncoupling of somatic and otolith growth rates in arctic char (*Salvelinus alpinus*) as an effect of differences in temperature response. Can. J. Fish. Aquat. Sci. 45:1514-1524; 1988.

223. Mucci, A. Influence of temperature on the composition of magnesian calcite overgrowths precipitated from seawater. Geochim. Cosmochim. Acta 51:1977-1984; 1987.

224. Mugiya, Y. Phase difference between calcification and organic matrix formation in the diurnal groth of otoliths in the rainbow trout. Fish. Bull. ,U. S. 85:395-401; 1987.

225. Mugiya, Y.; Hakomori, T.; Hatsutori, K. Trace metal incorporation into otoliths and scales in the goldfish, *Carassius auratus*. Comp. Biochem. Physiol. Pt. C 99(3):327-332; 1991.

226. Mugiya, Y.; Murumatsu, J. Time-marking methods for scanning electron microscopy in goldfish otoliths. Bull. JPN. Soc. Sci. Fish 48:1225-1232; 1982.

227. Mugiya, Y.; Oka, H. Biochemical relationship between otolith and somatic growth in the rainbow trout *Oncorhynchus mykiss* - Consequence of starvation, resumed feeding, and diel variations. Fish. Bull. ,U. S. 89(2):239-246; 1991.

228. Mugiya, Y.; Tanaka, S. Otolith development, increment formation, and an uncoupling of otolith to somatic growth rates in larval and juvenile goldfish. Nippon Suisan Gakkaishi 58(5):845-852; 1992.

229. Mugiya, Y.; Uchimura, T. Otolith resorption induced by anaerobic stress in the goldfish, *Carassius auratus*. J. Fish Biol. 35(6):813-818; 1989.

230. Mugiya, Y.; Watabe, N.; Yamada, J.; Dean, J.M.; Dunkelberger, D.G.; Shimizu, M. Diurnal rhythm in otolith formation in the goldfish *Carassius auratus*. Comp. Biochem. Physiol. Pt. A 68:659-662; 1981.

231. Mulligan, T.J. Stock identification by otolith composition. Proceedings of the stock identification workshop 193-194; 1987. (Abstract)

232. Murphy, M.D.; Taylor, R.G. Direct validation of ages determined for adult red drums from otolith sections. Trans. Amer. Fish Soc. 120(2):267-269; 1991.

233. Muth, R.T. Ontogeny and taxonomy of humpback chub, bonytail, and roundtail chub larvae and early juveniles. Fort Collins, Colorado: Ph.D. Dissertation. Colorado State University; 1990:1-262.

234. Muth, R.T.; Bestgen, K.R. Effect of sunlight on tetracycline marks in otoliths of Colorado squawfish larvae. Trans. Amer. Fish Soc. 120(5)):666-668; 1991.

235. Neilson, J.D. Sources of error in otolith microstructure examination. Stevenson, D.K.; Campana, S.E. eds. 115-126; 1992.

236. Neilson, J.D.; Campana, S.E. Comment on "larval fish age, growth, and body shrinkage: information available from otoliths". Can. J. Fish. Aquat. Sci. 47(12):2461-2462; 1990.

237. Neilson, J.D.; Green, G.H. Effects of feeding regimes and diel temperature cycles on otolith increment formation in juvenile chinook salmon *Oncorhynchus tshawytscha*. Fish. Bull. ,U. S. 83:91-101; 1985.

238. Nelson, C.S.; Northcote, T.G.; Hendy, C.H. Potential use of oxygen and carbon isotopic composition of otoliths to identify migratory and non-migratory stocks of the New Zeland common smelt: a pilot study. New Zealand Journal of Marine and Freshwater Research 23(3):337-344; 1989.

239. Nelson, W.C. High lake research and management in Colorado USA. Colorado Division of Wildlife,Special Report I-VI,1-41; 1988.

240. Nielson, J.D.; Green, G.H. Otoliths of chinook salmon *Oncorhynchus tshawytscha* daily growth increments and factors influencing their production. Can. J. Fish. Aquat. Sci. 39:1340-1347; 1982.

241. Nishimura, A. Occurrence of a check in otoliths of reared and sea-caught Larval Walleye Pollock Theragra chalcogramma (Pallas) and its relationship to events in early-life history. J. Exp. Mar. Biol. Ecol. 166(2):175-183; 1993.

242. Nishimura, A.; Yamada, J. Age and growth of larval and juvenile walley pollock, *Theragra chalcogramma* (Pallas), as determined by otolith daily growth increments. J. Exp. Mar. Biol. Ecol. 82:191-205; 1984.

243. NOLF, D. A survey of Perciform Otoliths and their interest for phylogenetic analysis, with an iconographic synopsis of the Percoidei. Bull. Mar. Sci. 51(1):220-239; 1993.

244. NOLF, D.; Cappetta, H. Otoliths of Pliocene fish from Southeastern France. Bull. Inst. R. Sci. Nat. Belg. Sci. Terre. 58:209-272; 1988.

245. NOLF, D.; Steurbat, E. Description of the first exclusively bathyal fish fauna from the Tertiary

in Europe otoliths from the lower Oligocene of the Pizzocorno layer Northern Italy. Bull. Inst. R. Sci. Nat. Belg. Sci. Terre. 57:217-230; 1987.

246. North, A.W. Age of antarctic fish: validation of the timing of annuli formation in otoliths and scales. Cybium 12(2):107-114; 1988.

247. Northcote, T.G.; Hendy, C.H.; Nelson, C.S.; Boubee, J.A.T. Tests for migratory history of the New Zealand common smelt (*Retropinna retropinna* (Richardson)) using otolith composition. Ecol. Freshw. Fish. 1(1):61-72; 1992.

248. Northcote, T.G.; Hendy, C.H.; Nelson, C.S.; Boubee, J.A.T. Tests for migratory history of the New Zealand common smelt (*Retropinna retropinna* (Richardson)) using otolith isotopic composition. Ecol. Freshw. Fish. 1:60-72; 1992.

249. Northcote, T.G.; Ward, F.J. Lake resident and migratory smelt, *Retropinna retropinna* (Richardson), of the lower Waidato River system, New Zealand. J. Fish Biol. 27:113-129; 1985.

250. Oliveira, A.M.; Farina, M.; Ludka, I.P.; Kachar, B. Vaterite, calcite, and aragonite in the otoliths of three species of Piranha. Naturwissenschaften 83:133-155; 1996.

251. Palmer, M.R.; Elderfield, H. Sr isotope composition of seawater over the past 75 Myr. Nature 314:526-528; 1985.

252. Palsson, O.K.; Jonsson, E.; Schopka, S.A.; Stefansson, G.; Steinarsson, B.A. Icelandic groundfish survey data used to improved precision in stock assessments. J. Northwest. Atl. Fish. Sci. 9:53-72; 1989.

253. Panfili, J.; Troadec, H. What's new in otolithometry? Suite au Symposium International "fish otolith research and application", Hilton Head Island (South Carolina, USA) - 23-27 Janvier 1993. Cybium 17(2):171-173; 1993.

254. Panfili, J.; Ximenes, M.C. Measurements on ground or sectioned otolith - Possibilities of bias.

J. Fish Biol. 41(2):201-208; 1992.

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

256. Pannella, G. Growth patterns in fish sagittae. Rhoads, D.C.; Lutz, R.A. eds. 519-560; 1980.

257. Papadopoulou, C.; Kanias, G.D.; Moraitoploulou-Kassimati, E. Trace element content in fish otoliths in relation to age and size. Mar. Pollut. Bull. 11:68-72; 1980.

258. Paragamian, V.L.; Bowles, E.C.; Hoelscher, B. Use of daily growth increments of otolith to assess stocking of hatchery-reared kokanees. Trans. Amer. Fish Soc. 121(6):785-791; 1992.

259. Pauly, D. Application of information on age and growth of fish to fishery management. Summerfelt, R.C.; Hall, G.E. eds. 485-506; 1987.

260. Pawson, M.G. Using otolith weight to age fish. J. Fish Biol. 36(4):521-532; 1990.

261. Penttila, J.; Dery, L.M. Age determination methods for northwest Atlantic species. NOAA Technical Report NMFS 72. Springfield, Virginia 22161: U.S.Department of Commerce, National Technical Information Service; 1988:1-135.

262. Perry, L.G.; Tranquilli, J.A. Age and growth of largemouth bass in a thermally altered reservoir as determined from otoliths. N. Amer. J. Fish. Mgmt. 4:321-330; 1984.

263. Perry, R.J.; McNaughton, P.A. Calcium regulation in neurons: transport processes. Curr. Opinion Neurobiol. 1:98-104; 1991.

264. Pidgeon, R.W.J. Age and growth of freshwater herring, *Potamalosa richmondia* Macleay (Clupeidae: Hyperlophinae), in the Bellringer River, New South Wales. Aust. J. Mar. Freshwat. Res. 40(6):679-692; 1989.

265. Poole, W.R.; Reynolds, J.D. Age and growth of yellow eel, *Anguilla anguilla* (L.), determined by two different methods. Ecol. Freshw. Fish. 5:86-95; 1996.

266. Popper, A.N.; Hoxter, B. Growth of a fish ear II. Locations of newly proliferated sensory hair cells in the saccular epithelium of *Astronotus ocellatus*. Hear. Res. 45(1-2):33-40; 1990.

267. Popper, A.N.; Tavolga, W.N. Structure and function of the ear in the marine catfish *Arius felis*. j comp physiol a sens neural behav physiol 144:27-34; 1981.

268. Prentice, J.A.; Dean, W.J.J. Use of known-age red drums to validate scale and otolith ages and to estimate growth in fresh water. N. Amer. J. Fish. Mgmt. 11(3):424-428; 1991.

269. Prince, E.D.; Lee, D.W.; Zweifel, J.R.; Brothers, E.B. Ageing young Atlantic blue marlin (*Makaira nigricans*) from otolith microstructure (summary paper). Anonymous295-305; 1990.

270. Radtke, R.L. Age and growth information available from the otoliths of the Hawaiian snapper *Pristipomoides filamentosus*. Coral Reefs 6:19-26; 1987.

271. Radtke, R.L. Strontium-Calcium concentration ratios in fish otoliths as environmental indicators. Comp. Biochem. Physiol. 92A(2):189-193; 1989.

272. Radtke, R.L. Larval fish age, growth, and body shrinkage: information available from otoliths. Can. J. Fish. Aquat. Sci. 46:1884-1894; 1989.

273. Radtke, R.L. Age determination of the Antarctic fishes *Champsocephalus gunnari* and *Notothenia rossii marmorata* from South Georgia. Polar Biol. 10(5):321-328; 1990.

274. Radtke, R.L. Information storage capacity of otoliths: Response to Neilson and Campana. Can. J. Fish. Aquat. Sci. 47(12):2463-2467; 1990.

275. Radtke, R.L.; Dean, J.M. Increment formation in the otoliths of embryos, larvae and juveniles of the mummichog *Fundulus heteroclitus*. Fish. Bull. ,U. S. 80:201-216; 1982.

276. Radtke, R.L.; Fine, M.L.; Bell, J. Somatic and otolith growth in the oyster toadfish *Opsanus tau*. J. Exp. Mar. Biol. Ecol. 90:259-276; 1985.

277. Radtke, R.L.; Hubold, G.; Folsom, S.D.; Lenz, P.H. Otolith structural and chemical analyses - the key to resolving age and growth of the Antarctic Silverfish, Pleuragramma antarcticum. Antarctic Science 5(1):51-62; 1993.

278. Radtke, R.L.; Kinsie III, R.A.; Folsom, S.D. Age at recruitment of Hawaiian freshwater gobies. Environ. Biol. Fishes 23(3):205-213; 1988.

279. Radtke, R.L.; Shafer, D.J. Environmental sensitivity of fish otolith microchemistry. Aust. J. Mar. Freshwat. Res. 43(5):935-951; 1992.

280. Radtke, R.L.; Shepherd, B.S. Current methodological refinements for the acquisition of life history information in fishes - Paradigms from pan-ocean billfishes. Comp. Biochem. Physiol. Pt. A 100(2):323-334; 1991.

281. Radtke, R.L.; Targett, T.E. Rhythmic structural and chemical patterns in otoliths of the Antarctic fish *Notothenia larseni*: Their application to age determination. Polar Biol. 3:203-210; 1984.

282. Radtke, R.L.; Townsend, D.W. Herring life history parameters resolved from structural and chemical analyses of otoliths. Anonymous53-70; 1990.

283. Radtke, R.L.; Townsend, D.W.; Folsom, S.D.; Morrison, M.A. Strontium - calcium concentration ratios in otoliths of herring larvae as indicators of environmental histories. Environ. Biol. Fishes 27(1):51-62; 1990.

284. Radtke, R.L.; Williams, D.F.; Hurley, P.C.F. The stable isotopic composition of bluefin tuna *Thunnus thynnus* otoliths evidence for physiological regulation. Comp. Biochem. Physiol. 87:797-802; 1987.

285. Rana, R.S. Freshwater fish otoliths from the Deccan Trap associated sedimentary Cretaceous-Tertiary transition beds of Rangapur Hyderabad district Andhra Pradesh India. Geobios. (Lyon) 21:465-494; 1988.

286. Reznick, D.; Lindbeck, E.; Bryga, H. Slower growth results in larger otoliths an experimental test with guppies *Poecilia reticulata*. Can. J. Fish. Aquat. Sci. 46:108-112; 1989.

287. Rhoads, D.C.; Lutz, R.A. Skeletal Growth of Aquatic Organisms. New York: Plenum Press; 1980:

288. Rice, J. Reliability of age and growth-rate estimates derived from otolith analysis. Summerfelt, R.C.; Hall, G.E. eds. 1: 3. 167-176; 1987.

289. Richter, H.; McDermott, J.G. The staining of fish otoliths for age determination. J. Fish Biol. 36(5):773-780; 1990.

290. Rijnsdorp, A.D.; Vanleeuwen, P.I.; Visser, T.A.M. On the validity and precision of back-calculation of growth from otoliths of the plaice, *Pleuronectes platessa* L. Fish. Res. 9(2):97-118; 1990.

291. Rodgers, K.; Chou, J.T.Y. Concentrations of inorganic ions in guinea-pig inner ear fluids. II. Post-mortem changes in the ionic composition of utricular endolymp and perilymph. J. Laryngol 80:885-889; 1966.

292. Rodhouse, P.G.; Hatfield, E.M.C. Age determination in squid using statolith growth increments. Fish. Res. 8: 1990.

293. Rogers, P.H.; Popper, A.N.; Hastings, M.C.; Saidel, W.M. Processing of acoustic signals in the auditory system of bony fish. J. Acoust. Soc. Am. 83:338-349; 1988.

294. Rubin, J.F.; Perrin, N. How does the body-scale model affect back-calculated growth -The example of Arctic charr, *Salvelinus alpinus* (L.), of Lake Geneva (Switzerland). Aquat. Sci.

52(3):287-295; 1990.

295. Sadovy, Y.; Severin, K.P. Trace elements in biogenic aragonite - Correlation of body growth rate and strontium levels in the otoliths of the white grunt, *Haemulon plumieri* (Pisces, Haemulidae). Bull. Mar. Sci. 50(2):237-257; 1992.

296. Saidel, W.M. Variations of trigger zones in vestibular afferent fibers of fish. Neurosci. Lett. 84:161-166; 1988.

297. Saitoh, S.; Yamada, J. Ultrastructure of the saccular epithelium and the otolithic membrane in relation to otolith growth in tilapia, *Oreochromis niloticus* (Teleostei, Cichlidae). Trans. Amer. Microsc. Soc. 108(3):223-238; 1989.

298. Savoy, T.F.; Crecco, V.A. Daily increments on the otoliths of larval American shad and their potential use in population dyamics studies. Summerfelt, R.C.; Hall, G.E. eds. 413-432; 1987.

299. Scarnecchia, D.L.; Hubert, W.A. Rapid removal of otoliths from salmonids (Comment). N. Amer. J. Fish. Mgmt. 7(2):312-313; 1987.

300. Schlueter, L.R. Simple removal of sagitta otoliths from walleyes. N. Amer. J. Fish. Mgmt. 9(1):123-124; 1988.

301. Schneider, R.C.; Smith, S.V. Skeletal Sr content and density in *Porites* spp. in relation to environmental factors. Mar. Biol. 66:121-131; 1982.

302. Schramm, H.L., Jr. Formation of annuli in otoliths of bluegills. Trans. Amer. Fish Soc. 118(5):546-555; 1989.

303. Schramm, H.L., Jr.; Malvestuto, S.P.; Hubert, W.A. Evaluation of procedures for back-calculation of lengths of largemouth bass aged by otoliths. N. Amer. J. Fish. Mgmt. 12(3):604-608; 1992.

304. Schramm, Jr.; Malvestuto, S.P.; Hubert, W.A. Evaluation of procedures for back-calculation of lengths of largemouth bass aged by otoliths. N. Amer. J. Fish. Mgmt. 12(3):604-608; 1992.

305. Schultz, D.L.; Taylor, R.S. Preparation of small otoliths for microscopic examination. N. Amer. J. Fish. Mgmt. 7(2):309-311; 1987.

306. Schultz, E.T. Daily otolith increments and the early life history of a viviparous fish, *Micrometrus minimus* (Embiotocidae). Copeia 1990(1):59-67; 1990.

307. Secor, D.H. Application of otolith microchemistry analysis to investigate anadromy in Chesapeake Bay Striped Bass Morone saxatilis. Fish. Bull. ,U. S. 90(4):798-806; 1992.

308. Secor, D.H.; Dean, J.M. Somatic growth effects on the otolith-fish size relationship i young pond-reared striped bass, *Morone saxatalis*. Can. J. Fish. Aquat. Sci. 46:113-121; 1989.

309. Secor, D.H.; Dean, J.M. Comparison of otolith-based back-calculation methods to determine individual growth histories of larval striped bass, *Morone saxatilis*. Can. J. Fish. Aquat. Sci. 49(7):1439-1454; 1992.

310. Secor, D.H.; Dean, J.M.; Campana, S.E. Recent Developments in Fish Otolith Research. Columbia: University of South Carolina Press; 1995:1-735.

311. Secor, D.H.; Dean, J.M.; Laban, E.H. Otolith removal and preparation for microstructural examination. Stevenson, D.K.; Campana, S.E. eds. 19-57; 1992.

312. Secor, D.H.; Henderson-Arzapalo, A.; Piccoli, P.M. Can otolith microchemistry chart patterns of migration and habitat utilization in anadromous fishes? J. Exp. Mar. Biol. Ecol. 192:15-33; 1995.

313. Seyama, H.; Edmonds, J.S.; Moran, M.J.; Shibata, Y.; Soma, M.; Morita, M. Periodicity in fish otolith Sr, Na, and K corresponds with visual banding. Experientia 47(11-12):1193-1195; 1991.

314. Simkiss, K. Calcium metabolism of fish in relation to ageing. Bagenal, T.B. ed. 1-12; 1974.

315. Skilbrei, O.T. Relationships between smolt length and growth and maturation in the sea of individually tagged Atlantic salmon (*Salmo salar*). Aquaculture 83(1-2):95-108; 1989.

316. Smith, M.K. Regional differences in otolith morphology of the deep slope red snapper *Etelis carbunculus*. Can. J. Fish. Aquat. Sci. 49(4):795-804; 1992.

317. Smith, S.V.; Buddemeier, R.W.; Redalje, R.C.; Houck, J.E. Strontium-calcium thermometry in coral skeletons. Science 204:404-407; 1979.

318. Sogard, S.M. Interpretation of otolith microstructure in juvenile winter flounder (*Pseudopleuronectes americanus*) - Ontogenetic development, daily increment validation, and somatic growth relationships. Can. J. Science 48(10):1862-1871; 1991.

319. Steurbat, E. Fish otoliths in paleontology. Natuurwet. Tijdschr. 64:1984); 1982.

320. Steurbat, E. Teleostean otoliths from the Oligo-Miocene from Aquitaine Southwestern France. Palaeontogr. Abt. A. Palaeozool-Stratigr. 186:1985); 1984.

321. Stevenson, D.K.; Campana Otolith microstructure examination and analysis. Ottawa, Canada: Canadian Special Publication of Fisheries and Aquatic Sciences 117; 1992:1-126.

322. Stuiver, M. Oxygen and carbon isotope ratios of fresh-water carbonates as climatic indicators. J. Geophys. Res. 75:5247-5257; 1970.

323. Summerfelt, R.C.; Hall, G.E. Age and Growth of Fish. Ames, Iowa: Iowa State University Press; 1987:1-544.

324. Suthers, I.M.; Fraser, A.; Frank, K.T. Comparison of lipid, otolith and morphometric condition indices of pelagic juvenile cod *Gadus morhua* from the Canadian Atlantic. Mar. Ecol. Prog. Ser. 84(1):31-40; 1992.

325. Svenning, M.A.; Smith-Nilsen, A.; Jobling, M. Sea water migration of Arctic charr (*Salvelinus*

alpinus L.) correlation between freshwater growth and seaward migration, based on back-calculation from otoliths. Nordic J. Freshwater Res. (67):18-26; 1992.

326. Sweatman, J.J.; Kohler, C.C. Validation of daily otolith increments for young-of-the-year white crappies. N. Amer. J. Fish. Mgmt. 11(4):499-503; 1991.

327. Tanaka, K.; Mugiya, Y.; Yamada, J. Effects of photoperiod and feeding on daily growth patterns in otoliths of juvenile *Tilapia nilotica*. Fish. Bull. ,U. S. 79:459-466; 1981.

328. Taubert, B.D.; Coble, D.W. Daily rings in otoliths of three species of *Lepomis* and *Tilapia mossambica*. J. Fish. Res. Bd. Can. 34 (3):332-340; 1977.

329. Taubert, B.D.; Tranquilli, J. Verification of the formation of annuli in otoliths of Largemouth Bass. Trans. Amer. Fish Soc. 111:531-534; 1982.

330. Thompson, K.R.; Beckman, D.W. Validation of age estimates from white sucker otoliths. Trans. Amer. Fish Soc. 124:637-639; 1995.

331. Thorpe, J.E. Environmental regulation of growth patterns in juvenile Atlantic salmon. Summerfelt, R.C.; Hall, G.E. eds. 463-474; 1987.

332. Thorrold, S.R.; Williams, D.M.B. Analysis of otolith microstructure to determine growth histories in larval cohorts of a tropical herring (*Herklotsichthys castelanaui*). Can. J. Fish. Aquat. Sci. 46:1615-1624; 1989.

333. Thorrold, S. Estimating some early life history parameters in a tropical clupeid, *Herklostsichthys castelnaui*, from daily growth increments in otoliths. Fish. Bull. ,U. S. 87(1):73-84; 1989.

334. Thorrold, S. Estimating some early life history parameters in a tropical clupeid, *Herklostsichthys castelnaui*, from daily growth increments in otoliths. Fish. Bull. ,U. S. 87(1):73-84; 1989.

335. Thresher, R.E. Session IV. Overview. Secor, D.H.; Dean, J.M.; Campana, S.E. eds. 631-632; 1995.

336. Titus, R.G.; Mosegaard, H. Selection for growth potential among migratory brown trout (*Salmo trutta*) fry competing for territories: evidence from otoliths. Can. J. Fish. Aquat. Sci. 48(1):19-27; 1991.

337. Toole, C.L.; Nielsen, R.L. Effects of microprobe precision on hypotheses related to otolith Sr:Ca ratios. Fishery Bulletin 90(2):421-427; 1992.

338. Townsend, D.M.; Radtke, R.L.; Morrison, M.A.; Folsom, S.D. Recruitment implications of larval herring overwintering distributions in the Gulf of Maine, inferred using a new otolith technique. Mar. Ecol. Prog. Ser. 55(1):1-13; 1989.

339. Townsend, D.W.; Radtke, R.L.; Corwin, S.; Libby, D.A. Strontium-calcium ratios in juvenile Atlantic herring *Clupea harengus* L otoliths as a function of water temperature. J. Exp. Mar. Biol. Ecol. 160(1):313-148; 1992.

340. Townsend, D.W.; Radtke, R.L.; Malone, D.P.; Wallinga, J.P. Use of otolith Strontium:Calcium ratios for hind-casting larval cod *Gadus morhua* distributions relative to water masses on Georges Bank. Mar. Ecol. Prog. Ser. 119:37-44; 1995.

341. Tsukamoto, K.; Kuwada, H.; Hirokawa, J.; Oya, M.; Sekiya, S.; et al. Size-dependent mortality of red sea bream, *Pagrus major*, juveniles released with flourescent otolith-tags in News Bay, Japan. J. Fish Biol. 35 SA:59-70; 1989.

342. Tsukamoto, K.; Seki, Y.; Oba, T.; Oya, M.; Iwahashi, M. Application of otolith to migration study of salmonids. Physiol. Ecol. Japan 1:119-140; 1989.

343. Tsukamoto, K.; Shima, Y. Otolith daily increment in sandfish. Nippon Suisan Gakkaishi 56(7):1083-1088; 1990.

344. Tzeng, W.-N. Relationship between growth rate and age at recruitment of *Anguilla japonica* elvers in a Taiwan estuary as inferred from otolith growth increments. Mar. Biol. 107(1):75-82; 1990.

345. Tzeng, W.-N.; Tsai, Y.C. Otolith microstructure and daily age of *Anguilla japonica*, Temminck & Schlegel Elvers from the estuaries of Taiwan with reference to unit stock and larval migration. J. Fish Biol. 40(6):845-858; 1992.

346. Tzeng, W.-N.; Yu, S.-Y. Validation of daily growth increments in otoliths of milkfish larvae by oxytetracycline labeling. Trans. Amer. Fish Soc. 118(2):168-174; 1989.

347. Tzeng, W.-N.; Yu, S.Y. Validation of daily growth increments in otoliths of milkfish larvae by oxytetracycline labeling. Trans. Amer. Fish Soc. 118:168-174; 1989.

348. Tzeng, W.-N.; Yu, S.Y. Effects of starvation on the formation of daily growth increments in the otoliths of milkfish, *Chanos chanos* (Forsskal), larvae. J. Fish Biol. 40(1):39-48; 1991.

349. Umezawa, A.; Tsukamoto, K. Determination of stock origin of the ayu based on the otolith microstructure. Nippon Suisan Gakkaishi 56(12):1919-1926; 1990.

350. Umezawa, A.; Tsukamoto, K. Factors influencing otolith increment formation in Japanese eel, *Anguilla japonica* T-and-S, elvers. J. Fish Biol. 39(2):211-223; 1991.

351. Vaillancourt, R.; Brethes J-C, F.; Desrosiers, G. Growth of the winter flounder *Pseudopleuronectes americanus* in the maritime estuary of the St. Lawrence Canada. Can. J. Zool. 63:1610-1616; 1985.

352. Valdez, R.A.; Ryel, R.J. Life History and Ecology of the Humpback chub (*Gila cypha*) in the Colorado River, Grand Canyon, Arizona. Salt Lake City, UT 84147: Final Report to Bureau of Reclamation, Upper Colorado River Region (Contract 0-CS-40-09110); 1995:1-286.

353. Velasco, J.C.; Rincon, P.A.; Lobon-Cervia, J. Age, growth and reproduction of the cyprinid

Rutilus lemmingii (Steindachner, 1866) in the River Huebra, Central Spain. J. Fish Biol. 36(4):469-480; 1990.

354. Vianet, R.; Quignard, J.-P.; Tomasini, J.-A. Age and growth of plaice, turbot, brill, and common sole (Pleuronectiformes) of the Gulf of Lion. Change in the structure of the sagittae. Cybium 13(3):247-258; 1989.

355. Victor, B.C.; Brothers, E.B. Age and growth of the fallfish, *Semotilus corporalis* with daily otolith increments as a method of annulus verification. Can. J. Zool. 60:2543-2550; 1982.

356. Volk, E.C.; Mortensen, D.G.; Wertheimer, A.C. Nondaily otolith increments and seasonal changes in growth of a pink salmon (*Onchorhychus gorbuscha*) population in Auke Bay, Alaska. Secor, D.H.; Dean, J.M.; Campana, S.E. eds. 211-225; 1995.

357. Volk, E.C.; Schroder, S.L.; Fresh, K.L. Inducement of banding patterns on the otoliths of juvenile chum salmon (*Oncorhynchus keta*). Proc. 1987 Northw. Pac. Pink Chum Salmon Workshop 206-217; 1987. (Abstract)

358. Wang, N.; Eckmann, R. Effects of photoperiod, feeding regime and water temperature on the formation of daily growth increments in otoliths of larval pike (*Esox lucius* L). J. Appl. Ichthyol. 8(1-4):246-250; 1992.

359. Ward, F.J.; Northcote, T.G.; Chapman, M.A. The effects of recent environmental changes in Lake Waahi on two forms of the common smelt *Retropinna retropinna*, and other biota. Water,Air,and Soil Pollution 32:427-443; 1987.

360. Watabe, N.; Tanaka, K.; Yamada, J.; Dean, J.M. Scanning electron microscope observations of the organic matrix in the otolith of the teleost fish *Fundulus heteroclitus* and *Tilapia nilotica*. J. Exp. Mar. Biol. Ecol. 58:127-134; 1982.

361. Weber, J.N. Incorporation of strontium into reef coral skeletal carbonate. Geochim. Cosmochim. Acta 37:2173-2190; 1973.

362. Werder, U. Age determination by scale analysis in juvenile matrincha *Brycon melanopterus* (Teleostei:Characoidei) a tropical characin from the Central Amazon. Amazoniana 7:445-464; 1983.

363. Wild, A.; Wexler, J.B.; Foreman, T.J. Extended studies of increment deposition rates in otoliths of yellowfin and skipjack tunas. Bull. Mar. Sci. 57:555-562; 1995.

364. Williams, T.; Bedford, B.C. The use of otoliths for age determination. Bagenal, T.B. ed. 114-123; 1974.

365. Wilson, C.D.; Boehlert, G.W. The effects of different otolith ageing techniques on estimates of growth and mortality for the splitnose rockfish, *Sebastes diploproa*, and canary rockfish, *S. pinniger*. California Fish and Game 76(3):146-160; 1990.

366. Wirt, L. Radioactivity in the environment - A case study of the Puerco and Little Colorado River basins, Arizona and New Mexico. U. S. G. S. Water Res. Invest. Rpt. 94-4192:1-23; 1994.

367. Wright, P.J. Calcium binding by soluble matrix of the otoliths of Atlantic salmon, *Salmo salar* L. J. Fish Biol. 38(4):625-628; 1991.

368. Wright, P.J. The influence of metabolic rate on otolith increment width in Atlantic salmon parr, *Salmo salar* L. J. Fish Biol. 38(6):929-934; 1991.

369. Wright, P.J.; Metcalfe, N.B.; Thorpe, J.E. Otolithy and somatic growth rates in Atlantic salmon parr, *Salmo salar* L.: evidence against coupling. J. Fish Biol. 36(2):241-250; 1990.

370. Wright, P.J.; Rowe, D.; Thorpe, J.E. Daily growth increments in the otoliths of Atlantic salmon parr, *Salmo salar* L, and the influence of environmental factors on their periodicity. J. Fish Biol. 39(1):103-114; 1991.

371. Wright, P.J.; Talbot, C.; Thorpe, J.E. Otolith calcification in Atlantic salmon parr, *Salmo salar* L and its relation to photoperiod and calcium metabolism. J. Fish Biol. 40(5):779-790; 1992.

372. Xiao, Y. How does somatic growth rate affect otolith size in fishes? Can. J. Fish. Aquat. Sci. 53:1675-1682; 1996.

373. Yancey, P.H.; Somero, G.N. Temperature dependace of intracellular pH: its role in the conservation of pyrurate apparent Km values in vertebrate lactate dehydrogenases. J. Comp. Physiol. 125:129-134; 1978.

374. Yoklavich, M.M.; Bailey, K.M. Hatching period, growth and survival of young walleye pollock *Theragra chalcogramma* as determined from otolith analysis. Mar. Ecol. Prog. Ser. 64(1-2):12-23; 1990.

375. Yoshida, H.; Kato, H. Relationship between the subopercle size and body length of walleye pollock *Theragra chalcogramma*. Onderstepoort. J. Vet. Res. 47:169-174; 1980.

376. Zhang, Z. Ultrastructure of otolith increments and checks in the teleost fish (*Oreochromis niloticus*). Morphol. 211(2):213-220; 1992.

377. Zhang, Z. Relationship of sacular ultrastructure to otolith growth in the teleost *Oreochromis niloticus*. J. Morphol. 21:1-10; 1992.

378. Zhang, Z. Relationship of saccular ultrastructure to otolith growth in the teleost *Oreochromis niloticus*. J. Morphol. 212(2):99-108; 1992.

379. Zhang, Z.; Moksness, E. Preliminary notes on age information from section of decalcified otolith of Atlantic herring. Fish. Res. 15(1992):181-186; 1992.

380. Zhang, Z.; Moksness, E. A chemical way of thinning otoliths of adult Atlantic Herring (Clupea harengus) to expose the microstructure in the nucleus region. Ices. J. Sci. 50(2):213-217; 1993.

381. Zhang, Z.; Runham, N.W. Temporal deposition of incremental and discontinuous zones in the otoliths of *Oreochromis niloticus*. J. Fish Biol. 40(3):333-340; 1992.

382. Zhang, Z.; Runham, N.W. Otolith microstructure pattern in *Oreochromis niloticus* (L). J. Fish Biol. 40(3):325-332; 1992.

383. Zhang, Z.; Runham, N.W. Effects of food ration and temperation level on the growth of *Oreochromis niloticus* (L) and their otoliths. J. Fish Biol. 40(3):341-350; 1992.

384. Zhang, Z.; Runham, N.W. Initial development of *Oreochromis niloticus* (Teleostei, Cichlidae) otolith. J. Zool. 227 P3:465-478; 1992.

TABLES

Table 1 - Numbers of humpback chub specimens used in this study by estimated annual age and river of capture.

Table 2 - Numbers and estimated dates of first lapillus increment formation for humpback chub deermined to be young of year (y.o.y. or age 0+) by calendar year and river of collection.

Table 1

Numbers of specimens aged by estimated annual age and river of capture

Age (years)	Mainstem Colorado	Little Colorado River	Totals
0+	21	73	94
1+	11	31	42
2+	0	3	3
3+	0	0	0
4+ or 5+	0	3	3
6+ or 7+	0	3	3
8+ or 9+	1	5	6
10+ to 14+	0	6	6
15+ to 19+	0	5	5
>= 20+	0	1	1
Totals	33	130	163

Table 2

Numbers and estimated dates of first lapillus increment formation for humpback chubdetermined to be young of year (yoy or age 0+) by calendar year and river of collection

Year Collected	Estimated dates of first increment formation in specimens collected in mainstem Colorado River					Estimated dates of first increment formation in specimens collected in Little Colorado River				
	N	earliest	mean	latest	collection dates	N	earliest	mean	latest	collection dates
1990	3		5/30*		10/20	9	3/12	3/24	4/11	5/15 & 10/18
1991	1		5/26		9/13	30	4/27	5/15	5/30	6/14 - 7/14
1992	5	5/7	5/18	6/18	6/24 & 9/24	11	4/17	5/7	6/27	4/30 - 7/9
1993	12	5/13	6/11	7/28	6/26 - 9/10	11	4/10	4/26	5/10	5/1 - 6/3
Totals	21					61				

* one specimen aged with daily precision. Abnormalities of otoliths of others precluded increment counts.

FIGURES

Figure 1. Size distribution of humpback chub specimens used in this study.

Figure 2. Lengths and estimated ages of all post young of year humpback chub specimens used in this study.

Figure 3. Frequencies of year classes (based on estimated ages) in overall sample of humpback chub.

Figure 4. Lengths and estimated ages of all young of year humpback chub specimens used in this study.

Figure 1

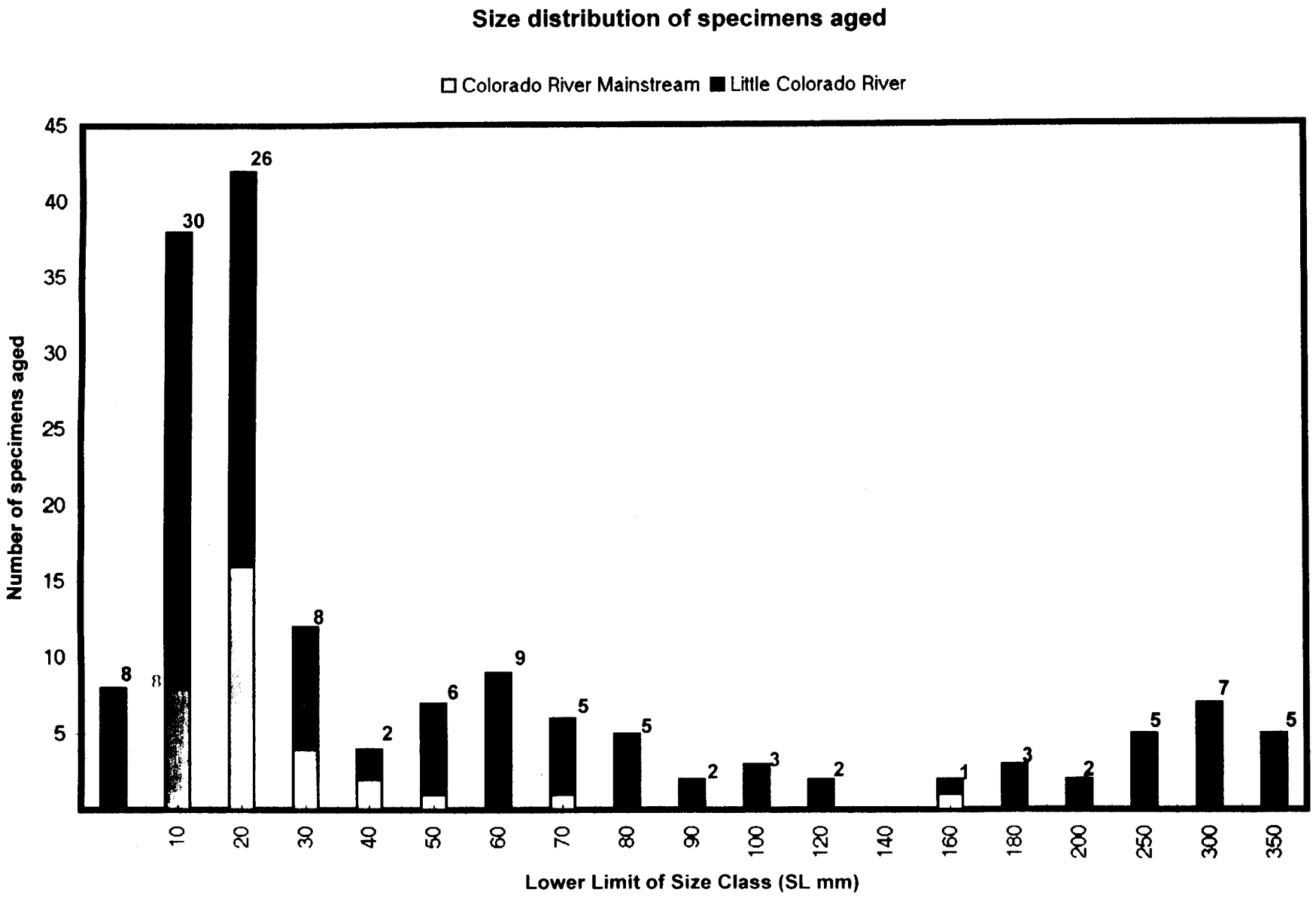

Size distribution of specimens aged
Colorado River Mainstream
Little Colorado River
Number of specimens aged
45
40
35
30
25
20
15
10
5
8
30
26
8
2
6
9
5
5
2
3
2
1
3
2
5
7
5
10
20
30
40
50
60
70
80
90
100
120
140
160
180
200
250
300
350
Lower Limit of Size Class (SL mm)

Figure 2

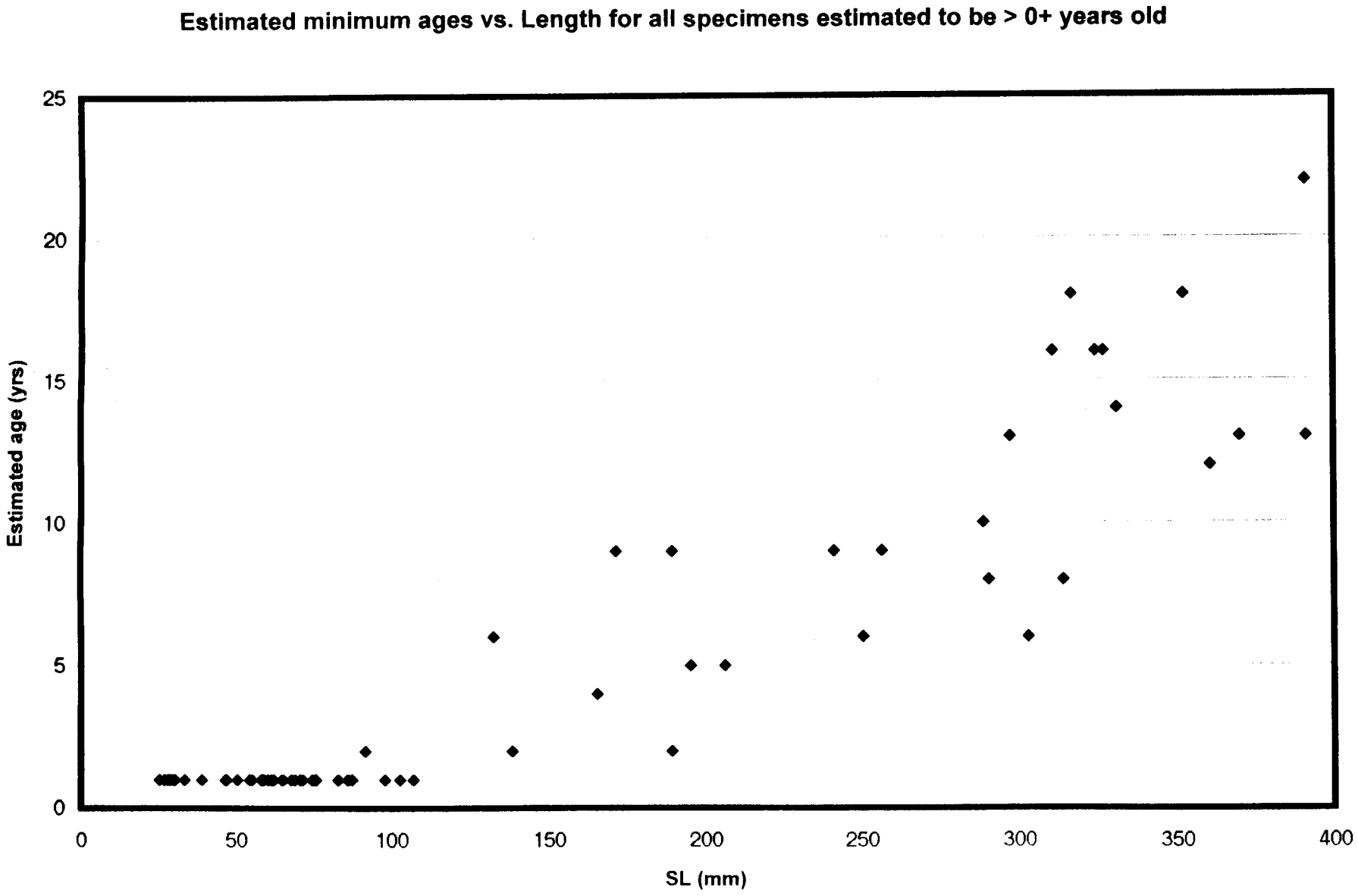

Estimated minimum ages vs. Length for all specimens estimated to be > 0+ years old
Estimated age (yrs)
25
20
15
10
5
0
0
50
100
150
200
250
300
350
400
SL (mm)

Figure 3

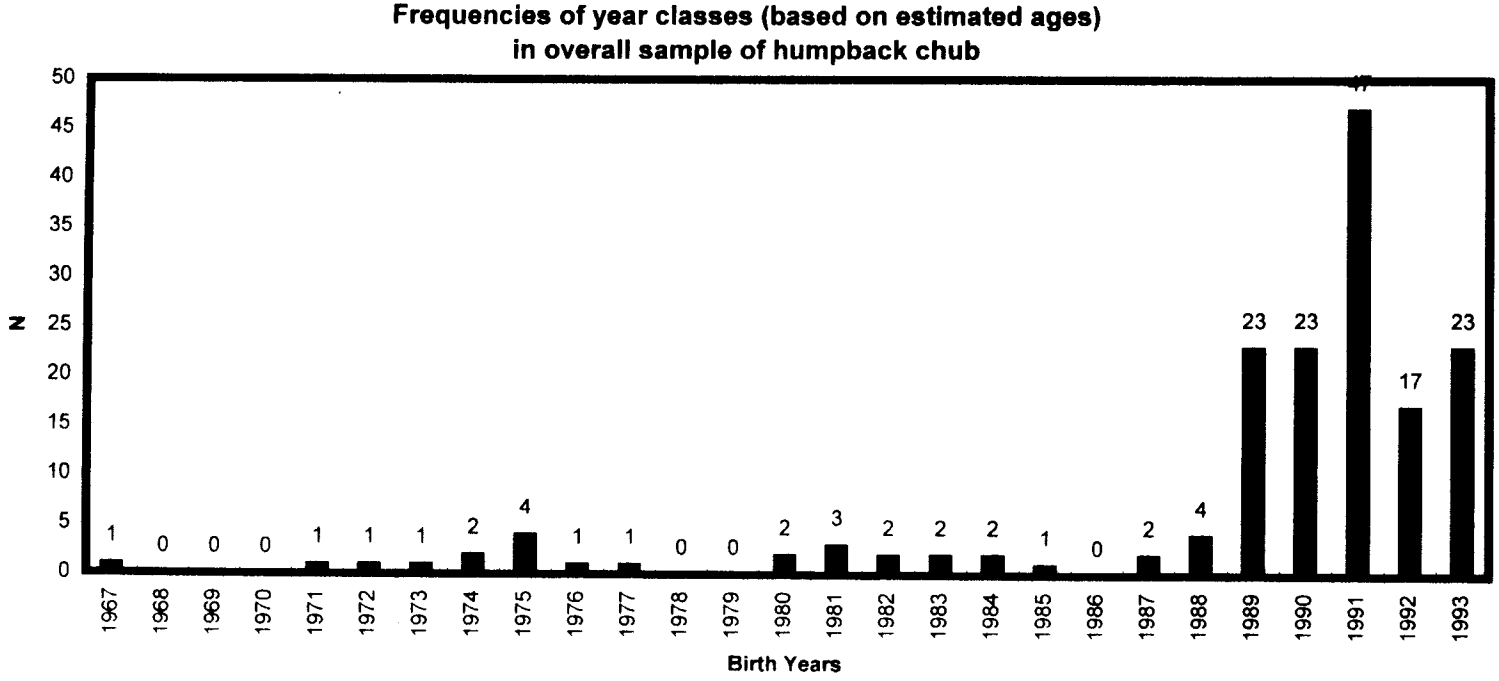
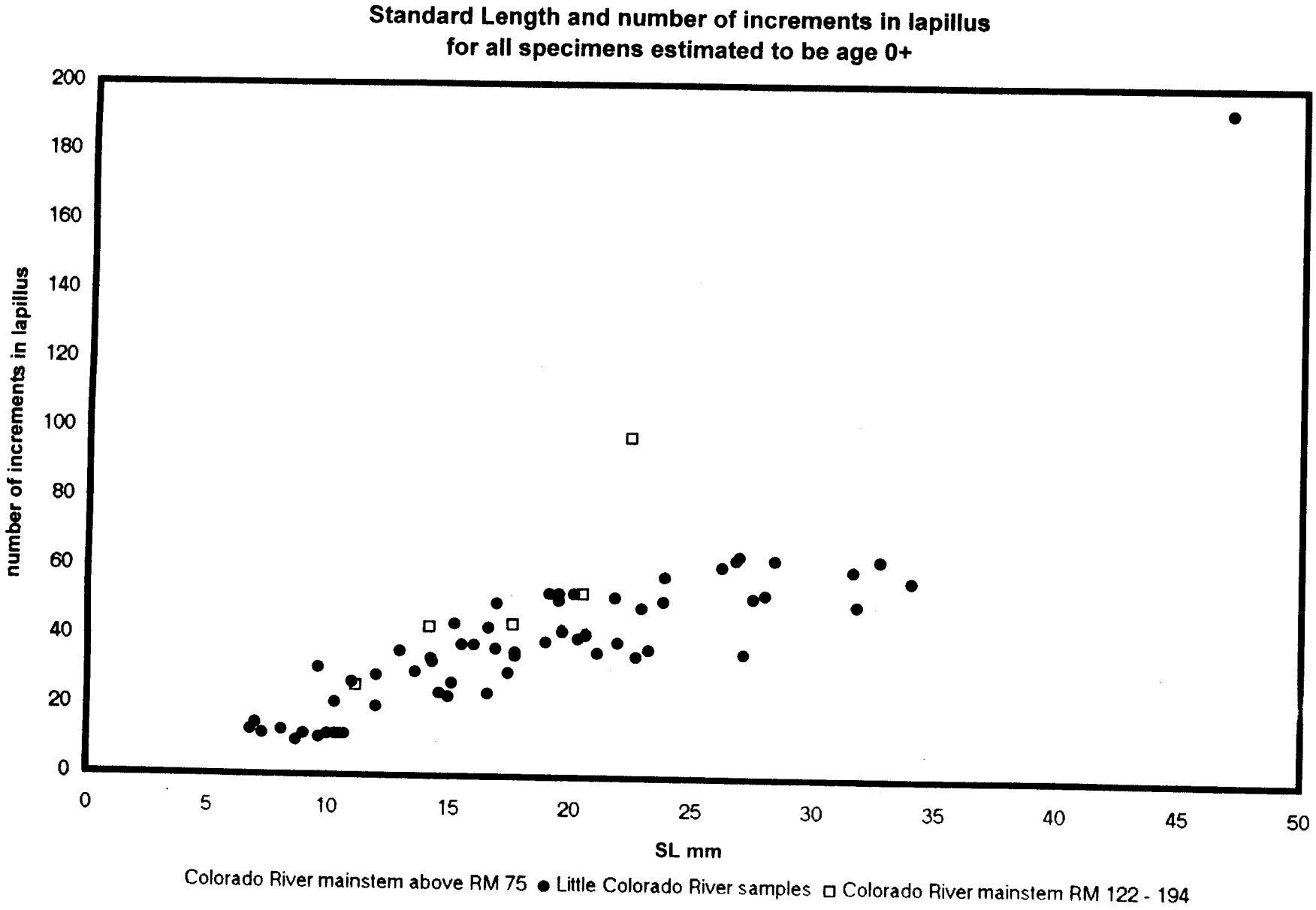

Frequencies of year classes (based on estimated ages)
in overall sample of humpback chub
N
50
45
40
35
30
25
20
15
10
5
0
1 0 0 0 1 1 1 2 4 1 1 0 0 2 3 2 2 2 1 0 2 4 23 23 47 17 23
1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993
Birth Years

Figure 4


Standard Length and number of increments in lapillus
for all specimens estimated to be age 0+
number of increments in lapillus
200
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
35
40
45
50
SL mm
Colorado River mainstem above RM 75 ● Little Colorado River samples □ Colorado River mainstem RM 122 - 194

APPENDIX A - LIST OF ALL SPECIMENS FROM WHICH OTOLITHS WERE EXAMINED IN THIS STUDY.

CAPTURE LOCALITY	River mile	DATE CAPTURED	CALCULATED OR ACTUAL SL (MM)	MIN AGE (YRS) (LAP)	MAX AGE (YRS) (LAP)	MEAN ESTIMATE OF YEAR CLASS
LCR: ABOUT 250 M ABOVE MOUTH	250.00	5/28/89	391	22	23	1967
LCR: AT MOUTH	50.00	5/15/89	317	18	18	1971
0/ PARA TRAM	50.00	5/1/90	352	18	18	1972
LCR: ABOUT 250 M ABOVE MOUTH	250.00	5/15/89	324	16	16	1973
9650/ SALT TRAIL CAMP	9650.00	5/15/90	311	16	16	1974
0/ PARA TRAM	50.00	4/20/90	327	16	16	1974
LCR 200 M ABOVE MOUTH	200.00	5/9/89	331	14	14	1975
LCR SALT CANYON	9650.00	5/2/89	297	13	16	1975
LCR AT MOUTH	50.00	5/23/89	370	13	15	1975
LCR ABOUT 250 M ABOVE MOUTH	250.00	5/26/89	391	13	14	1976
LCR AT MOUTH	50.00	5/25/89	361	12	13	1977
LCR SALT CANYON	9650.00	5/6/89	289	10	18	1975
LCR: FOUR MILES ABOVE MOUTH	6400.00	5/17/89	241	9	10	1980
COLORADO RIVER MAINSTEM RM 63 9L	63.90	10/22/90	172	9	10	1981
100/ HOOP	100.00	5/8/90	189	9	9	1981
180/ NS D HOOP	180.00	5/9/90	256	9	9	1981
LCR: ABOUT 250 M ABOVE MOUTH	250.00	5/8/89	314	8	10	1980
192/ SS D HOOP	192.00	5/7/90	290	8	9	1982
LCR: SALT CANYON	9650.00	5/2/89	303	6	8	1982
LCR: 4 MILES ABOVE MOUTH	6400.00	5/17/89	251	6	6	1983
LCR 1/4 MI ABOVE COLORADO MAIN	400.00	10/18/90	133	6	7	1984
LCR: 4 MILES ABOVE MOUTH	6500.00	5/17/89	195	5	5	1984
9650/ SALT TRAIL CAMP	9650.00	5/15/90	206	5	5	1985
180/ NS D HOOP	180.00	5/7/90	166	4	10	1983
LCR: ATOMIZER FALLS	12000.00	5/6/89	92	2	2	1987
LCR: 1225 M ABOVE MOUTH	1255.00	5/17/89	189	2	2	1987
9650/ SALT TRAIL CAMP	9650.00	5/15/90	139	2	2	1988
LCR: NEAR SALT CANYON	9650.00	5/4/89	103	1	1	1988
LCR. ATOMIZER FALLS	12000.00	5/6/89	107	1	1	1988
LCR: 1225 M ABOVE MOUTH	1225.00	5/24/89		1	1	1988
COLORADO: 0 2 MI ABOVE CARDENAS		10/22/90	59	1	1	1989
1200/ HOOP	1200.00	4/20/90	47	1	1	1989
5432/ SIPAPU	5432.00	4/26/90	51	1	1	1989
5432/ SIPAPU	5432.00	4/26/90	55	1	1	1989
5432/ SIPAPU	5432.00	4/26/90	55	1	1	1989
5432/ SIPAPU	5432.00	4/26/90	58	1	1	1989
9650/ SALT TRAIL CAMP	9650.00	5/15/90	59	1	1	1989
5432/ SIPAPU	5432.00	4/26/90	60	1	1	1989
5432/ SIPAPU	5432.00	4/26/90	65	1	1	1989
5432/ SIPAPU	5432.00	5/2/90	68	1	1	1989
5432/ SIPAPU	5432.00	4/26/90	69	1	1	1989
5432/ SIPAPU	5432.00	4/26/90	71	1	1	1989
5432/ SIPAPU	5432.00	5/8/90	72	1	1	1989
9650/ SALT TRAIL CAMP	9650.00	5/15/90	76	1	1	1989
1200/ HOOP	1200.00	4/20/90	83	1	1	1989
5432/ SIPAPU	5432.00	5/8/90	83	1	1	1989
5432/ SIPAPU	5432.00	5/8/90	86	1	1	1989
180/ NS D HOOP	180.00	5/3/90	86	1	1	1989
5432/ SIPAPU	5432.00	4/26/90	88	1	1	1989
5432/ SIPAPU	5432.00	5/8/90	98	1	1	1989
0/LCR WARM CONTROL		5/5/90	68	1	1	1989
0/LCREXPERIMENTAL		5/5/90	75	1	1	1989
0/COLO. COLD CONTROL		5/5/90	76	1	1	1989
COLORADO RIVER AT RM 122.5	122.50	4/6/91	28	1	1	1990
COLORADO RIVER AT RM 122.5	122.50	4/6/91	29	1	1	1990
COLORADO RIVER AT RM 122.5	122.50	4/6/91	30	1	1	1990
COLORADO RIVER AT RM 70.3	7.03	5/12/91	34	1	1	1990
COLORADO RIVER AT RM 193.9	193.90	5/23/91	47	1	1	1990
AGFD: MILE 1800: LCR: RIGHT	1800.00	3/30/91	59	1	1	1990
AGFD: REACH 22: MILE 1800	1800.00	5/2/91	61	1	1	1990
AGFD: MILE 1800: LCR: RIGHT	1800.00	3/30/91	61	1	1	1990
AGFD: MILE 1800: LCR RIGHT	1800.00	3/30/91	62	1	1	1990
AGFD: REACH 22: MILE 1900M	1900.00	5/13/91	65	1	1	1990
AGFD: REACH 22: MILE 1800	1800.00	5/2/91	107	1	1	1990
COLORADO RIVER AT RM 64.5	64.50	6/24/92	25	1	1	1991
COLORADO RIVER AT RM 64.5	64.50	6/24/92	27	1	1	1991
COLORADO RIVER AT RM 64.5	64.50	4/15/92	30	1	1	1991
COLORADO RIVER AT RM 122.0	122.00	4/18/92	39	1	1	1991
Shinumo Creek at Colorado River Mile 108.6R	108.60	9/12/93	75	1	1	1992

CAPTURE LOCALITY	River mile	DATE CAPTURED	CALCULATED OR ACTUAL SL (MM)	TL (MM)	Mean estimated date 1st increment formation	MIN AGE (YRS) (LAP)	MAX AGE (YRS) (LAP)
MAINSTEM COLORADO: RM 65.3 L	65.30	10/20/90	28	33	5/30/90	0	0
COLORADO RIVER MAINSTEM: RM70.9	70.90	10/22/90	29	37	#VALUE!	0	0
COLORADO MAINSTEM: RM 65.3 L	65.30	10/20/90	50	58	#VALUE!	0	0
9650/ SALT TRAIL CAMP	9650.00	5/15/90	13	16	4/9/90	0	0
9650/ SALT TRAIL CAMP	9650.00	5/15/90	14	18	4/11/90	0	0
9650/ SALT TRAIL CAMP	9650.00	5/15/90	17	22	3/26/90	0	0
9650/ SALT TRAIL CAMP	9650.00	5/15/90	20	25	3/23/90	0	0
9650/ SALT TRAIL CAMP	9650.00	5/15/90	24	31	3/18/90	0	0
9650/ SALT TRAIL CAMP	9650.00	5/15/90	27	36	3/13/90	0	0
9650/ SALT TRAIL CAMP	9650.00	5/15/90	27	36	3/12/90	0	0
9650/ SALT TRAIL CAMP	9650.00	5/15/90	28	37	3/13/90	0	0
LCR - 1/4 MILE UP	750.00	10/18/90	47	55	4/4/90	0	0
COLORADO RIVER AT RM 68.1	68.10	9/13/91	29	34	5/26/91	0	0
AGFD: REACH 22: MILE 9970	9970.00	6/14/91	10		5/13/91	0	0
AGFD: REACH 22: MILE 9400	9400.00	6/23/91	15	18	5/30/91	0	0
AGFD: REACH 22: MILE 1830	1830.00	6/27/91	15		5/13/91	0	0
AGFD: REACH 22: MILE 1850	1850.00	6/20/91	16	20	5/13/91	0	0
AGFD: REACH 22: MILE 9970	9970.00	6/14/91	16	20	5/7/91	0	0
AGFD: REACH 22: MILE 9400	9400.00	6/23/91	17	21	5/28/91	0	0
AGFD: REACH 22: MILE 1790	1790.00	6/30/91	17	22	5/17/91	0	0
AGFD: REACH 22: MILE 1850	1850.00	6/20/91	18	23	5/15/91	0	0
AGFD: REACH 22: MILE 7.0 K	7000.00	6/16/91	18	23	5/12/91	0	0
AGFD: REACH 22: MILE 9400	9400.00	6/23/91	19	23	5/13/91	0	0
AGFD: REACH 22: MILE 1920	1920.00	6/28/91	19		5/6/91	0	0
AGFD: REACH 22: MILE 1790	1790.00	6/30/91	20	27	5/7/91	0	0
AGFD: REACH 22: MILE 1854	1854.00	6/27/91	20	25	5/7/91	0	0
AGFD: REACH 22: MILE 9400	9400.00	6/23/91	20	26	5/11/91	0	0
AGFD: REACH 22: MILE 9970	9970.00	6/14/91	20	26	5/4/91	0	0
AGFD: REACH 22: MILE 9970	9970.00	6/14/91	21	27	5/4/91	0	0
AGFD: REACH 22: MILE 1790	1790.00	6/30/91	22	29	5/8/91	0	0
AGFD: REACH 22: MILE 9400	9400.00	6/23/91	22	27	5/14/91	0	0
AGFD: REACH 22: MILE 1830	1830.00	6/27/91	23	30	5/22/91	0	0
AGFD: REACH 22: MILE 1790	1790.00	6/30/91	23	30	5/11/91	0	0
AGFD: REACH 22: MILE 7.0 K	7000.00	6/16/91	23	30	5/9/91	0	0
AGFD: REACH 22: MILE 1855	1855.00	7/11/91	24		5/20/91	0	0
AGFD: REACH 22: MILE 1855	1855.00	7/11/91	26		5/10/91	0	0
AGFD: REACH 22: MILE 1830	1830.00	6/27/91	27	35	5/21/91	0	0
AGFD: REACH 22: MILE 1855	1855.00	7/11/91	28	34	5/19/91	0	0
AGFD: REACH 22: MILE 1855	1855.00	7/11/91	28		5/19/91	0	0
AGFD: REACH 22: MILE 1855	1855.00	7/11/91	32	39	5/11/91	0	0
AGFD: REACH 22: MILE 0010	10.00	7/14/91	32	42	5/25/91	0	0
AGFD: REACH 22: MILE 1790	1790.00	6/30/91	33	43	4/27/91	0	0
AGFD: REACH 22: MILE 1855	1855.00	7/11/91	34	42	5/14/91	0	0
AGFD: REACH=MAIN (FOR LCREXPERIMENT - CAPTURED IN LCR)		7/14/91	24	31	5/21/91	0	0
AGFD: REACH=MAIN (FOR LCREXPERIMENT - CAPTURED IN LCR)		7/14/91	24	29	5/23/91	0	0
AGFD: REACH=MAINSTREAM		7/11/91	26	34	5/20/91	0	0
AGFD: REACH=MAIN (FOR LCREXPERIMENT - CAPTURED IN LCR)		7/14/91	27	32	5/18/91	0	0
AGFD: REACH=MAIN (FOR LCREXPERIMENT - CAPTURED IN LCR)		7/14/91	28	34	5/14/91	0	0
AGFD: REACH=MAIN (FOR LCREXPERIMENT - CAPTURED IN LCR)		7/14/91	28	36	5/23/91	0	0
AGFD: REACH=MAIN (FOR LCREXPERIMENT - CAPTURED IN LCR)		7/14/91	29	37	5/22/91	0	0
AGFD: REACH=MAIN (FOR LCREXPERIMENT - CAPTURED IN LCR)		7/14/91	29	34	5/22/91	0	0
AGFD: REACH=MAIN (FOR LCREXPERIMENT - CAPTURED IN LCR)		7/14/91	30	39	5/12/91	0	0
AGFD: REACH=MAIN (FOR LCREXPERIMENT - CAPTURED IN LCR)		7/14/91	32	41	5/22/91	0	0
AGFD: REACH=MAIN (FOR LCREXPERIMENT - CAPTURED IN LCR)		7/14/91	34	44	5/21/91	0	0
AGFD: REACH=MAIN (FOR LCREXPERIMENT - CAPTURED IN LCR)		7/14/91	36	47	5/4/91	0	0
COLORADO RIVER AT RM 68.1	68.10	6/24/92	14		5/14/92	0	0
COLORADO RIVER AT RM 122.1	122.10	6/26/92	14	18	5/14/92	0	0
COLORADO RIVER AT RM 68.1	68.10	6/24/92	14		5/7/92	0	0
COLORADO RIVER AT RM 68.1	68.10	6/24/92	20		5/10/92	0	0
COLORADO RIVER AT RM 192.3	192.30	9/24/92	22	26	6/18/92	0	0
LCR: 3360M ABOVE MOUTH	3360.00	7/9/92	7		6/27/92	0	0
LCR: 4128M ABOVE MOUTH	4128.00	6/27/92	8	9	6/8/92	0	0
LCR: 2973M ABOVE MOUTH	2973.00	5/15/92	9	10	5/5/92	0	0
LCR: 3830M ABOVE MOUTH	3830.00	5/10/92	10	10	4/29/92	0	0
LCR: 2070M ABOVE MOUTH	2070.00	4/30/92	10		4/18/92	0	0
LCR: 2070M ABOVE MOUTH	2070.00	4/30/92	11		4/18/92	0	0
LCR: 2980M ABOVE MOUTH	2980.00	5/23/92	11	13	4/26/92	0	0

CAPTURE LOCALITY	River mile	DATE CAPTURED	CALCULATED OR ACTUAL SL (MM)	TL (MM)	Mean estimated date 1st increment formation	MIN AGE (YRS) (LAP)	MAX AGE (YRS) (LAP)
LCR: 9575M ABOVE MOUTH	9575.00	5/10/92	12		4/20/92	0	0
LCR: 2370M ABOVE MOUTH	2370.00	7/9/92	14	15	6/9/92	0	0
LCR: 3090M ABOVE MOUTH	3090.00	5/21/92	14		4/18/92	0	0
LCR: 798M ABOVE MOUTH	798.00	5/24/92	17		4/17/92	0	0
[illegible]	193.85	6/26/93	11	13	5/31/93	0	0
COLORADO RIVER, RIVER MILE 65.25 L	65.20	7/28/93	15	19	5/30/93	0	0
[illegible]	44.20	7/23/93	18	21	6/2/93	0	0
[illegible]	192.40	6/26/93	18	21	5/13/93	0	0
[illegible]	193.85	8/4/93	20	25	6/12/93	0	0
Colorado River Mile 65.25L	65.25	9/8/93	21	24	7/28/93	0	0
Colorado River Mile 68.39R	68.39	9/9/93	22	30	6/26/93	0	0
Colorado River Mile 65.25L	65.25	9/8/93	24	32	6/24/93	0	0
Colorado River Mile 65.25L	65.25	9/8/93	26	34	6/2/93	0	0
Colorado River Mile 74.46R	74.46	9/10/93	26	34	6/16/93	0	0
Colorado River Mile 63.08L	63.08	9/8/93	30	39	6/10/93	0	0
Colorado River Mile 65.25L	65.25	9/8/93	34	44	6/4/93	0	0
LCR: 12517M ABOVE MOUTH	12517.00	5/20/93	7		5/7/93	0	0
LCR: 12517M ABOVE MOUTH	12517.00	5/20/93	7		5/5/93	0	0
LCR: 12002M ABOVE MOUTH	12002.00	5/20/93	9		5/8/93	0	0
LCR: 10550M ABOVE MOUTH	10550.00	5/1/93	10	11	4/10/93	0	0
LCR: 10550M ABOVE MOUTH	10550.00	5/1/93	10	11	4/19/93	0	0
LCR: 9540M ABOVE MOUTH	9540.00	5/1/93	11		4/19/93	0	0
LCR: 11599M ABOVE MOUTH	11599.00	5/20/93	12		4/13/93	0	0
LCR: 7080 M ABOVE MOUTH	7080.00	6/3/93	15		5/10/93	0	0
LCR: 3098 M ABOVE MOUTH	3098.00	5/20/93	15		4/23/93	0	0
LCR: 7080 M ABOVE MOUTH	7080.00	6/3/93	17		5/4/93	0	0
LCR: 7080 M ABOVE MOUTH	7080.00	6/3/93	21		4/28/93	0	0

APPENDIX B - LIST OF OTHER SPECIMENS PROVIDED TO THE AUTHOR BY AGFD BUT NOT USED IN THIS STUDY, OR FROM WHICH OTOLITHS WERE LOST (GENERALLY DUE TO DECALCIFICATION DURING PRESERVATION OR LOSS/DESTRUCTION DURING HANDLING)

CAPTURE LOCALITY	River mile	DATE CAPTURED	CALCULATED OR ACTUAL SL (MM)	TL (MM)
BUBBLING PONDS HATCHERY		5/5/93		
BUBBLING PONDS HATCHERY		5/6/93		
BUBBLING PONDS HATCHERY		5/7/93		
BUBBLING PONDS HATCHERY		5/9/93		
BUBBLING PONDS HATCHERY		5/10/93		
BUBBLING PONDS HATCHERY		5/11/93		
BUBBLING PONDS HATCHERY		5/12/93		
BUBBLING PONDS HATCHERY		5/13/93		
BUBBLING PONDS HATCHERY		5/14/93		
BUBBLING PONDS HATCHERY		5/15/93		
BUBBLING PONDS HATCHERY		5/16/93		
BUBBLING PONDS HATCHERY		5/17/93		
BUBBLING PONDS HATCHERY		5/19/93		
BUBBLING PONDS HATCHERY		6/5/93		
BUBBLING PONDS HATCHERY		6/9/93		
BUBBLING PONDS HATCHERY		6/12/93		
BUBBLING PONDS HATCHERY		7/19/93		
BUBBLING PONDS HATCHERY				
BUBBLING PONDS HATCHERY				
AGFD; MILE 22; REACH 1750		7/7/91	13	16
9650/ SALT TRAIL CAMP		5/15/90	14	18
9650/ SALT TRAIL CAMP		5/15/90	15	19
9650/ SALT TRAIL CAMP		5/15/90	15	18
9650/ SALT TRAIL CAMP		5/15/90	15	20
9650/ SALT TRAIL CAMP		5/15/90	16	20
AGFD; REACH 22; MILE 0900		6/21/91	16	19
9650/ SALT TRAIL CAMP		5/15/90	16	20
LCR; 7080 M ABOVE MOUTH		6/3/93	16	20
9650/ SALT TRAIL CAMP		5/15/90	16	21
9650/ SALT TRAIL CAMP		5/15/90	17	20
9650/ SALT TRAIL CAMP		5/15/90	17	21
9650/ SALT TRAIL CAMP		5/15/90	17	20
AGFD; MILE 22; REACH 1750		7/7/91	17	21
9650/ SALT TRAIL CAMP		5/15/90	17	22
9650/ SALT TRAIL CAMP		5/15/90	18	24
AGFD; MILE 22; REACH 1750		7/7/91	18	23
2400/ RUN RIFFLE		5/6/90	18	23
9650/ SALT TRAIL CAMP		5/15/90	18	23
8ELO FALLS		5/6/90	19	23
9650/ SALT TRAIL CAMP		5/15/90	19	24
AGFD; REACH 22; MILE 2200		6/20/91	19	23
9650/ SALT TRAIL CAMP		5/15/90	19	24
BELOW FALLS		5/6/90	19	25
9650/ SALT TRAIL CAMP		5/15/90	19	24
9650/ SALT TRAIL CAMP		5/15/90	20	26
9650/ SALT TRAIL CAMP		5/15/90	20	25
2400/ RUN RIFFLE		5/6/90	20	25
9650/ SALT TRAIL CAMP		5/15/90	20	26
AGFD; REACH 22; MILE 0010		7/11/91	20	24
AGFD; MILE 22; REACH 1750		7/7/91	20	26
9650/ SALT TRAIL CAMP		5/15/90	20	26
9650/ SALT TRAIL CAMP		5/15/90	20	26
9650/ SALT TRAIL CAMP		5/15/90	21	27
9650/ SALT TRAIL CAMP		5/15/90	21	27
110/SIDE CHANNEL AT MOUTH		5/7/90	21	27
AGFD; REACH 22; MILE 0010		7/11/91	21	25
AGFD; REACH 22; MILE 0010		7/14/91	21	24
9650/ SALT TRAIL CAMP		5/15/90	21	27
9650/ SALT TRAIL CAMP		5/15/90	21	28
AGFD; MILE 22; REACH 1750		7/7/91	21	28
110/SIDE CHANNEL AT MOUTH		5/7/90	21	27
110/SIDE CHANNEL AT MOUTH		5/7/90	21	27

CAPTURE LOCALITY	River mile	DATE CAPTURED	CALCULATED OR ACTUAL SL (MM)	TL (MM)
AGFD; MILE 22; REACH 1750		7/7/91	22	28
AGFD; REACH 22; MILE 0010		7/11/91	22	28
AGFD; MILE 22; REACH 1750		7/7/91	22	27
AGFD; REACH 22; MILE 0010		7/11/91	22	29
9650/ SALT TRAIL CAMP		5/15/90	22	29
110/SIDE CHANNEL AT MOUTH		5/7/90	22	29
110/SIDE CHANNEL AT MOUTH		5/7/90	23	29
110/SIDE CHANNEL AT MOUTH		5/7/90	23	29
AGFD; REACH 22; MILE 0010		7/11/91	23	24
AGFD; REACH 22; MILE 1855		7/11/91	23	28
AGFD; REACH 22; MILE 1855		7/11/91	23	28
AGFD; REACH 22; MILE 2500		7/6/91	23	28
AGFD; REACH 22; MILE 10760		7/1/91	23	29
AGFD; MILE 22; REACH 1750		7/7/91	24	31
9650/ SALT TRAIL CAMP		5/15/90	24	31
110/SIDE CHANNEL AT MOUTH		5/7/90	24	31
9650/ SALT TRAIL CAMP		5/15/90	25	34
9650/ SALT TRAIL CAMP		5/15/90	26	35
AGFD; REACH 22; MILE 0010		7/11/91	26	32
9650/ SALT TRAIL CAMP		5/15/90	26	34
2400/ RUN RIFFLE		5/6/90	26	34
592/ L SIDE MT		5/12/90	27	31
9650/ SALT TRAIL CAMP		5/15/90	27	36
AGFD; REACH 22; MILE 0010		7/11/91	27	34
550/ R SIDE MT		5/12/90	27	32
9650/ SALT TRAIL CAMP		5/15/90	28	36
AGFD; REACH 22; MILE 1855		7/11/91	28	33
AGFD; REACH 22; MILE 0010		7/11/91	29	34
380/ L SIDE MT		5/12/90	29	34
550/ R SIDE MT		5/12/90	29	34
AGFD; REACH 22; MILE 1855		7/11/91	30	36
380/ L SIDE MT		5/12/90	32	37
AGFD; REACH 22; MILE 1855		7/11/91	35	43
180/ NS D HOOP		5/12/90	44	52
LCR - 1/4 MI. UP		10/18/90	55	64
5432/ SIPAPU		5/11/90	55	72
1200/ HOOP		4/20/90	57	
5432/ SIPAPU		5/2/90	61	73
621/ HOOP		5/14/90	66	86
5432/ SIPAPU		5/8/90	69	91
5432/ SIPAPU		5/8/90	71	95
5432/ SIPAPU		4/26/90	72	91
5432/ SIPAPU		5/8/90	74	98
5432/ SIPAPU		5/8/90	74	98
5432/ SIPAPU		4/26/90	75	95
5432/ SIPAPU		4/26/90	75	95
5432/ SIPAPU		5/2/90	75	94
5432/ SIPAPU		4/26/90	75	94
5432/ SIPAPU		5/8/90	76	101
5432/ SIPAPU		4/26/90	77	96
5432/ SIPAPU		4/26/90	77	97
5432/ SIPAPU		4/26/90	78	97
5432/ SIPAPU		5/2/90	78	99
5432/ SIPAPU		5/8/90	78	106
5432/ SIPAPU		4/26/90	78	97
5432/ SIPAPU		4/26/90	79	100
5432/ SIPAPU		5/2/90	81	102
5432/ SIPAPU		5/8/90	81	104
5432/ SIPAPU		5/8/90	82	105
5432/ SIPAPU		5/2/90	82	103
9904/ HOOP		5/5/90	83	97
5432/ SIPAPU		4/26/90	83	103

CAPTURE LOCALITY	River mile	DATE CAPTURED	CALCULATED OR ACTUAL SL (MM)	TL (MM)
5432/ SIPAPU		5/8/90	83	110
5432/ SIPAPU		5/8/90	84	110
5432/ SIPAPU		5/8/90	84	109
5432/ SIPAPU		5/2/90	84	107
5432/ SIPAPU		4/26/90	85	105
5432/ SIPAPU		5/8/90	85	111
5432/ SIPAPU		5/2/90	86	92
200/ HOOP		4/20/90	87	113
LCR; 200 M ABOVE CONFLUENCE		5/7/89	89	104
LCR; ATOMIZER FALLS		5/6/89	89	105
1/4 MILE UP LCR		10/18/90	89	105
1200/ HOOP		5/11/90	90	113
5432/ SIPAPU		5/8/90	90	118
LCR; ATOMIZER FALLS		5/6/89	90	106
5432/ SIPAPU		5/5/90	91	119
192/ SS D HOOP		4/21/90	92	119
5432/ SIPAPU		5/8/90	93	119
5432/ SIPAPU		5/8/90	94	117
5432/ SIPAPU		5/2/90	95	119
LCR; ATOMIZER FALLS		5/6/89	100	118
AGFD; REACH 22; MILE 1920		5/5/91	100	118
LCRMO @ CONFLUENCE		4/28/90	101	119
LCR; ATOMIZER FALLS		5/6/89	103	121
AGFD; REACH 22; MILE 1800		3/30/91	111	130
LCR		5/5/89	111	131
AGFD; REACH 22; MILE 1920		5/3/91	115	135
13654/ HOOP		5/2/90	121	142
9904/ HOOP		5/9/90	123	145
LCR; AT MOUTH		5/9/89	149	175
LCR; 1225 M ABOVE MOUTH		5/24/89	155	182
9650/ SALT TRAIL CAMP		5/15/90	177	208
192/ SS D HOOP		5/8/90	193	227
LCR; 100 M ABOVE BIG CANYON		5/4/89	200	235
9650/ SALT TRAIL CAMP		5/15/90	206	243
9650/ SALT TRAIL CAMP		5/15/90	209	246
100/ HOOP		5/8/90	209	246
180/ NS D HOOP		5/1/90	212	250
1225/ HOOP		5/1/90	219	258
LCR; 1225 M ABOVE MOUTH		5/8/89	233	274
LCR; ATOMIZER FALLS		5/6/89	236	278
5432/ SIPAPU		5/8/90	240	283
180/ NS D HOOP		5/9/90	244	287
LCR; ATOMIZER FALLS		5/6/89	262	309
LCR; SALT CANYON		5/11/89	271	319
LCR; 975 M ABOVE CONFLUENCE		5/23/88	280	330
LCR; AT MOUTH		5/9/89	280	330
LCR; 975 M ABOVE CONFLUENCE		5/23/88	290	342
LCR; 975 M ABOVE CONFLUENCE		5/23/88	294	346
LCR; AT SALT CANYON		5/13/89	297	350
LCR; 975 M ABOVE CONFLUENCE		5/23/88	298	351
9650/ SALT TRAIL CAMP		5/15/90	298	351
0/ PARA TRAM		4/20/90	299	352
LCRMO; PARA TRAM			299	352
100/ HOOP		4/23/90	300	353
LCR; 975 M ABOVE CONFLUENCE		5/23/88	301	355
LCR; 598 M ABOVE MOUTH		5/6/89	309	364
LCR; AT MOUTH		5/9/89	313	369
LCR; AT MOUTH		5/5/89	314	370
LCR; AT MOUTH		5/26/89	316	372
LCR; AT MOUTH		5/7/89	328	386
90/ ANGLING		5/10/90	331	390
LCR; 1860 M ABOVE MOUTH		5/21/91		

CAPTURE LOCALITY	River mile	DATE CAPTURED	CALCULATED OR ACTUAL SL (MM)	TL (MM)
LCR; 1860 M ABOVE MOUTH		5/21/91		
LCR; 1860 M ABOVE MOUTH		5/21/91		
LCR; 1860 M ABOVE MOUTH		5/21/91		
LCR; 1930 M ABOVE MOUTH		5/31/91		
LCR; 1930 M ABOVE MOUTH		5/31/91		
LCR; 1930 M ABOVE MOUTH		5/31/91		
LCR; 1930 M ABOVE MOUTH		5/31/91		
LCR; 1930 M ABOVE MOUTH		5/31/91		
LCR; 1930 M ABOVE MOUTH		5/31/91		
LCR; 1930 M ABOVE MOUTH		5/31/91		
LCR; 1930 M ABOVE MOUTH		5/31/91		
LCR; 1930 M ABOVE MOUTH		5/31/91		
LCR; 1930 M ABOVE MOUTH		5/31/91		
LCR; 1930 M ABOVE MOUTH		5/31/91		
LCR; 3235 M ABOVE MOUTH		7/9/92		
LCR; 10132 M ABOVE MOUTH		7/22/92		
LCR; 3065 M ABOVE MOUTH		5/20/93		
LCR; 3050 M ABOVE MOUTH		5/22/93		
LCR; 3065 M ABOVE MOUTH		6/5/93		
LCR; 3065 M ABOVE MOUTH		6/5/93		
LCR; 2580 M ABOVE MOUTH		6/5/93		
LCR; 4088 M ABOVE MOUTH		6/5/93		
LCR; 4088 M ABOVE MOUTH		6/5/93		
LCR; 2070M ABOVE MOUTH		4/30/92		
LCR; 2070M ABOVE MOUTH		4/30/92		
LCR; 2070M ABOVE MOUTH		4/30/92		
LCR; 13215M ABOVE MOUTH		5/3/93		
LCR; 4405M ABOVE MOUTH		5/15/92		
LCR; 13215M ABOVE MOUTH		5/3/93		
LCR; 2970M ABOVE MOUTH		5/20/92		
LCR; 9561M ABOVE MOUTH		5/10/92		
LCR; 2970M ABOVE MOUTH		5/20/92		
LCR; 7600M ABOVE MOUTH		5/14/92		
LCR; 2970M ABOVE MOUTH		5/20/92		
LCR; 9560M ABOVE MOUTH		5/8/92		
LCR; 3740M ABOVE MOUTH		5/10/92		
LCR; 11805M ABOVE MOUTH		5/3/93		
LCR; 2070M ABOVE MOUTH		4/30/92		
LCR; 3970M ABOVE MOUTH		5/10/92		
LCR; 2973M ABOVE MOUTH		5/15/92		
LCR; 2973M ABOVE MOUTH		5/15/92		
LCR; 10550M ABOVE MOUTH		5/1/93		
LCR; 10550M ABOVE MOUTH		5/1/93		
LCR; 10550M ABOVE MOUTH		5/1/93		
LCR; 10550M ABOVE MOUTH		5/1/93		
LCR; 10550M ABOVE MOUTH		5/1/93		
LCR; 10550M ABOVE MOUTH		5/1/93		
LCR; 10550M ABOVE MOUTH		5/1/93		
LCR; 10550M ABOVE MOUTH		5/1/93		
LCR; 10550M ABOVE MOUTH		5/1/93		
AGFD; REACH 22; MILE 1855		7/11/91		
180/ NS D HOOP		5/12/90		
180/ NS D HOOP		4/26/90		
5432/ SIPAPU		5/8/90		
5432/ SIPAPU		5/8/90		
550/ R SIDE MT		5/12/90		
LCR				
LCR; 1225 M ABOVE MOUTH		5/24/89		
LCR; 1225 M ABOVE MOUTH		5/24/89		
LCR; 1225 M ABOVE MOUTH		5/24/89		
LCR		5/15/89		
LCR		5/15/89		
LCR		5/15/89		
LCR		5/15/89		

CAPTURE LOCALITY	River mile	DATE CAPTURED	CALCULATED OR ACTUAL SL (MM)	TL (MM)
LCR		5/15/89		
LCR		5/15/89		
LCR		5/15/89		
LCR		5/15/89		
LCR		5/15/89		
LCR		5/15/89		
LCR: FOUR MILES ABOVE MOUTH		5/14/89		
AGFD; REACH=MAIN (FOR LCREXPERIMENT - CAPTURED IN LCR)		7/14/91	26	32
AGFD; REACH=MAIN (FOR LCREXPERIMENT - CAPTURED IN LCR)		7/14/91	30	36
0/LCREXPERIMENTAL		5/5/90	63	83
0/LCR WARM CONTROL		5/5/90	64	85
0/COLO. COLD CONTROL		5/5/90	66	87
0/LCR WARM CONTROL		5/5/90	73	98
0/LCREXPERIMENTAL		5/5/90	75	100
0/COLO. COLD CONTROL		5/5/90	81	
0/LCR WARM CONTROL		5/5/90	82	108
0/LCREXPERIMENTAL		4/26/90	83	108
0/LCREXPERIMENTAL		5/5/90	84	110
0/COLO. COLD CONTROL		5/5/90	87	109
0/COLO. COLD CONTROL		5/5/90	88	113
0/LCR WARM CONTROL		5/5/90	91	115

APPENDIX C - INTERIM PROJECT REPORT OF FEBRUARY 5, 1993