Final Project Report

to

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

by

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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....
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> 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.
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> 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.

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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 <u>mainstem Colorado River</u>					Estimated dates of first increment formation in specimens collected in <u>Little Colorado River</u>				
	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

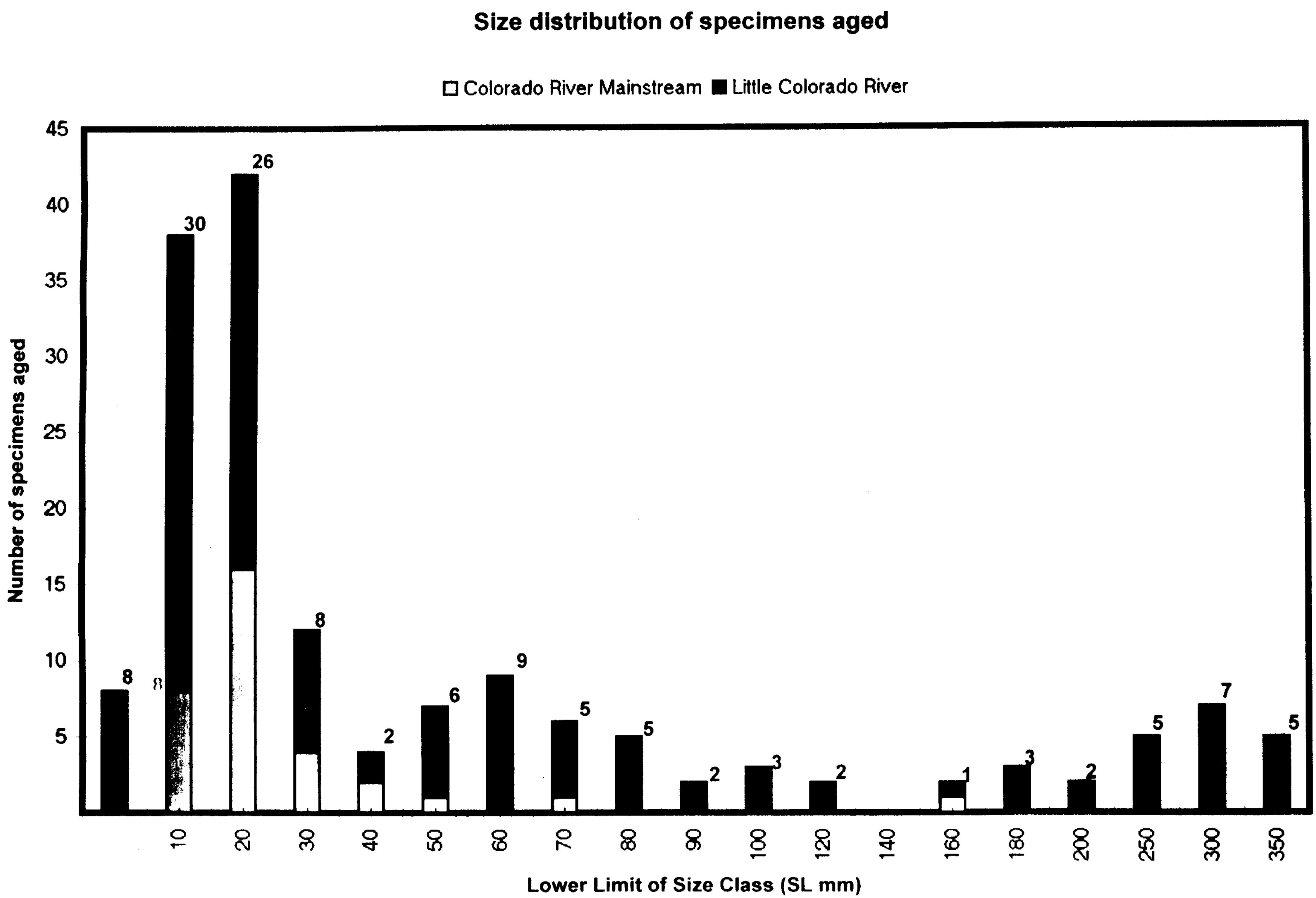

Size distribution of specimens aged
Colorado River Mainstream
Little Colorado River
Number of specimens aged
45
40
35
30
25
20
15
10
5
8
8
30
26
8
2
6
9
5
5
2
3
2
1
3
2
5
7
5
10
20
30
40
50
60
70
80
90
100
120
140
160
180
200
250
300
350
Lower Limit of Size Class (SL mm)

Figure 2

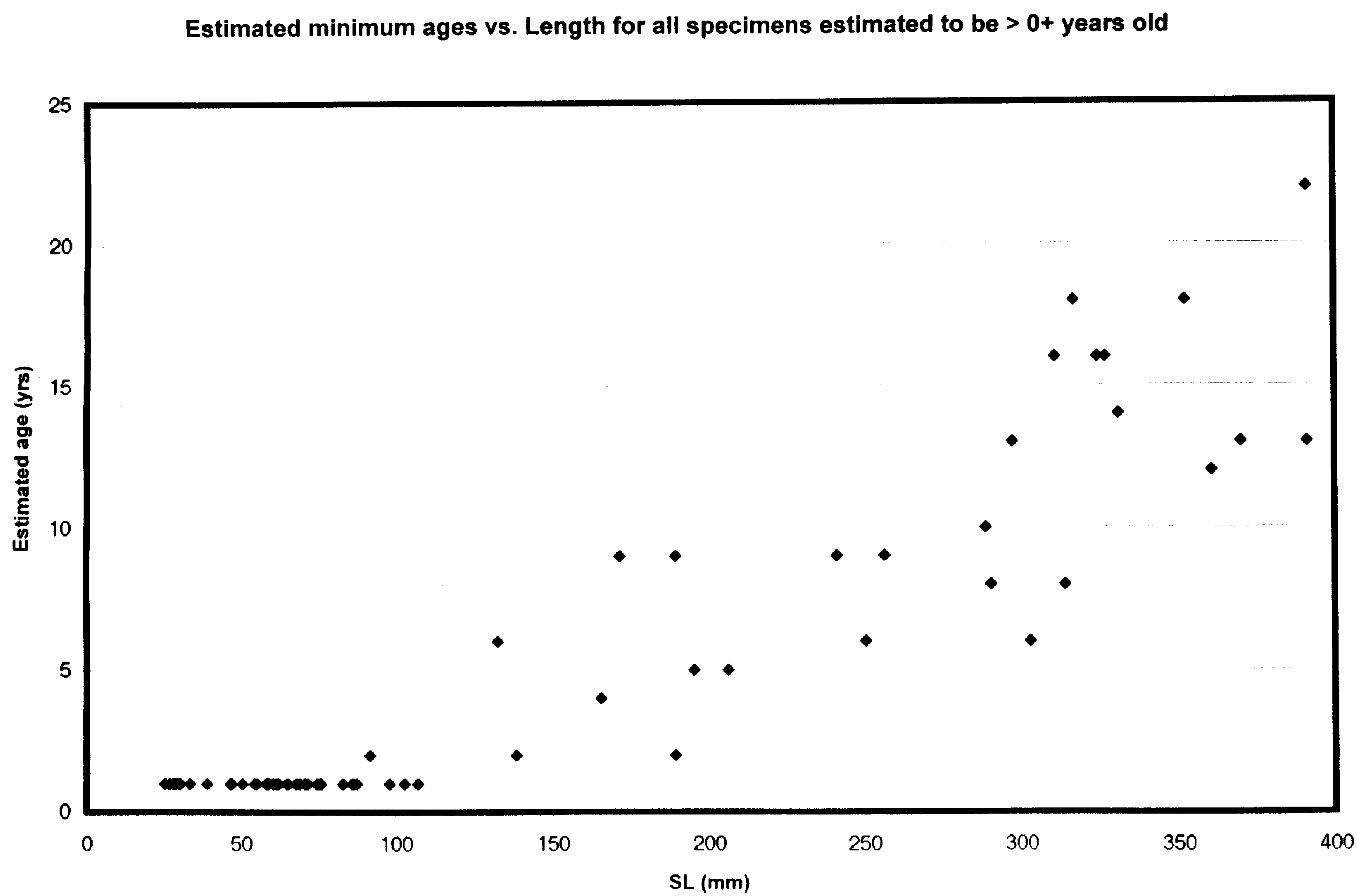

Estimated minimum ages vs. Length for all specimens estimated to be > 0+ years old
Estimated age (yrs)
0
5
10
15
20
25
0
50
100
150
200
250
300
350
400
SL (mm)

Figure 3

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

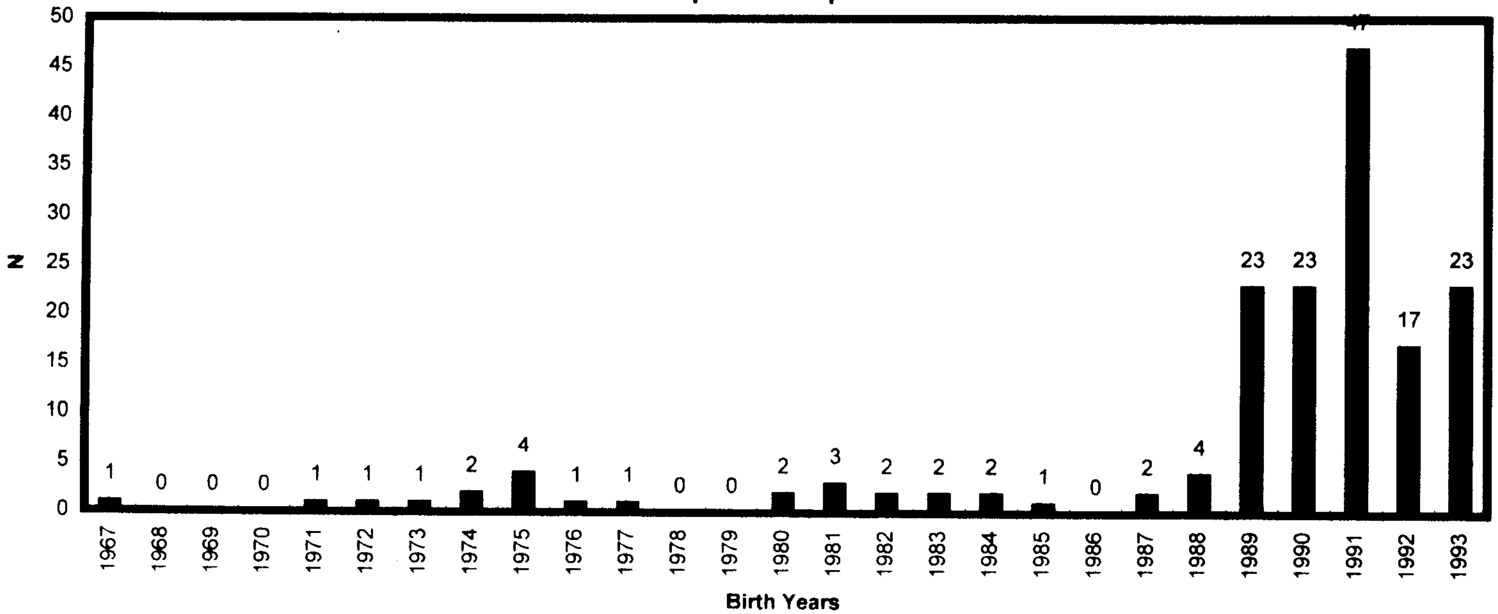
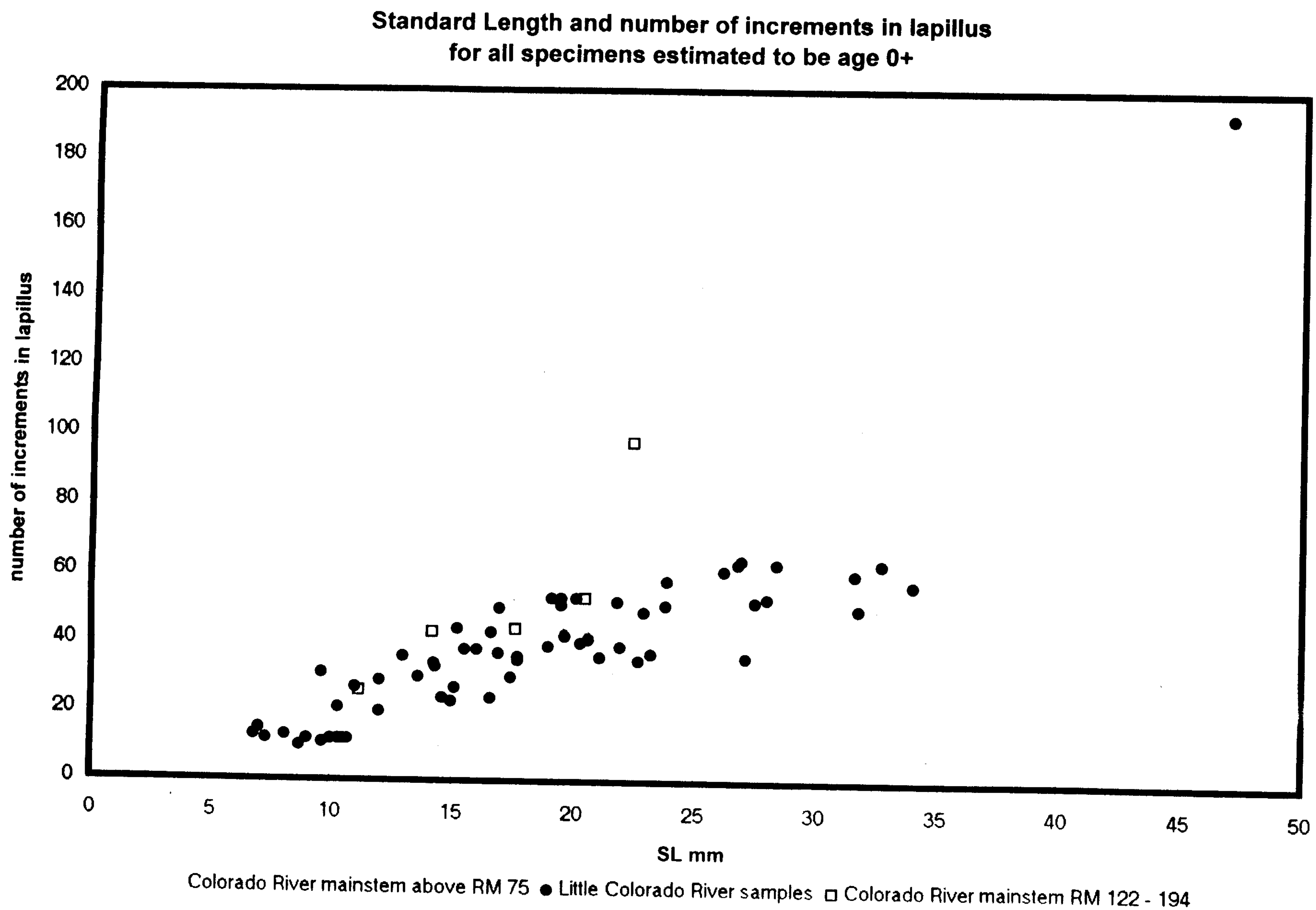


Figure 4


Standard Length and number of increments in lapillus
for all specimens estimated to be age 0+
number of increments in lapillus
0
20
40
60
80
100
120
140
160
180
200
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
COLORADO RIVER, RIVER MILE 193.85 R, CB	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
COLORADO RIVER, RIVER MILE 44.27 L CB	44.20	7/23/93	18	21	6/2/93	0	0
COLORADO RIVER, RIVER MILE 192.4 R, CB	192.40	6/26/93	18	21	5/13/93	0	0
COLORADO RIVER, RIVER MILE 193.85 CF	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; 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		
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