AN OVERVIEW OF STATUS AND TREND INFORMATION FOR THE GRAND CANYON POPULATION OF THE HUMPBACK CHUB, *Gila Cypha*[1]

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For the
Glen Canyon Dam Adaptive Management Work Group
Ad Hoc Committee on Humpback chub
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[1] Includes a critique of past population estimates and stock assessment model outputs – see Appendix 1.

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CURRENT STOCK ASSESSMENT METHODS IN SUPPORT OF ADAPTIVE MANAGEMENT FOR GRAND CANYON HUMPBACK CHUB

Recent analyses of historical data on humpback chub in Grand Canyon have caused considerable consternation, because of uncertainties about the current size of the population and because of the strong probability that the population has been declining steadily for at least a decade. Our most recent assessment models indicate that the current spawning population is probably somewhere between 2000 and 4000 age 4 and older fish, i.e. suggesting this population might be considered as contributing to ESA delisting based on the current population abundance, but has likely declined by at least 50% since 1990, i.e. does not meet the stable population criterion for delisting. We remain quite uncertain about the absolute population size because of uncertainties about whether field procedures have met some assumptions of the main method used to estimate absolute abundance (mark-recapture sampling) and because of limited sample sizes, but all the assessment methods are in clear agreement about the population being in decline. This includes not only the mark-recapture population estimates, but also several population trend indices based on catch-per-effort in sampling gear that has been fished consistently over the years. Only one trend indexing method, trammel netting in the Colorado River mainstem, fails to indicate a downward trend in abundance.

One assessment model (called “Supertag”) resulted in a considerably lower estimate for recent adult abundance (1100-1200 fish in 2001), but we now believe that estimate was biased downward because of using two inappropriate assumptions in the calculations: the population was assumed to have a stable age structure in the early 1990s, and older chubs were assumed to be equally vulnerable to sampling programs. Grand Canyon assessments and data analyses are greatly complicated by the migratory life history of the chubs that spawn in the Little Colorado River and by inconsistency over the years in when the fish have been sampled relative to the timing of the spawning migration. Older fish are over-represented in samples taken in the LCR during spawning runs, but are underrepresented in samples taken there outside the spawning season. The opposite effect occurs in mainstem sampling. Further, there are indications that older fish do not spawn every year, making them less vulnerable to sampling when sampling effort was/is concentrated in the LCR where it is easy to catch fish for marking. The Supertag method did not account for these complexities in interpretation of historical data.

There are two strategic options for monitoring and population assessment in Grand Canyon: (1) make independent population (and/or trend index) estimates each year using multiple-trip mark-recapture experiments (mark fish on successive trips and measure the proportion of the population made up by these “known” marked numbers) along with index catch-per-effort sampling; and/or (2) use more elaborate stock assessment models to integrate current and past information into more complex estimators of current abundance. It should be noted that virtually all fisheries management programs for important harvested fish stocks are based on integrated assessment approaches, particularly considering that annual point estimates can “bounce around” a lot due to chance sampling factors so that if each estimate were taken too seriously there would be inappropriate (unnecessary or even dangerous) management responses to those chance factors. It might make scientists more comfortable to pretend that only the most recent, independently collected data are to be used for calculating population size, without any assumptions about historical data, however at some point the noisy independent estimates must be somehow integrated into longer term assessments of population change.   One way to do that integration is to plot the independent estimates then use visual or statistical regression methods to identify trend patterns; the problem with this simple "state reconstruction" approach is that it fails to offer guidance about causes of decline (e.g. changes in recruitment of young fish versus changes in survival rate) and to properly weight estimates of varying quality due to changes over the years in sampling methods, locations, etc.

Within-year methods for stock assessment using mark-recapture experiments are easily understood. We go out and mark a known number of fish with PIT tags, then examine what proportion of later samples are made up of these individuals. So for example if we mark 500 fish, and find that marked fish are 20% of the fish seen in recapture samples later that year, we would conclude that 500 is 20% of the population size, i.e. the population size was 2500. It does not, of course, work this nicely in the field. The percentage of fish marked in recapture samples can vary a lot by chance alone (luck of the draw), marked fish may be less vulnerable to capture later than unmarked ones (wariness, movement induced by sampling), movement of fish into and out of the marking region may dilute the mark rate, and there may be differential loss of tagged fish or tags. So any single point estimate must be treated with great caution.

More complex assessment models, such as the ones we have called "ASMR" (Age-Specific Mark-Recapture) and "Supertag" in Grand Canyon studies, attempt to integrate information and estimates over time by using knowledge or assumptions about how the observations are linked through population dynamics processes. That is, we first build an accounting model for population changes (how the numbers of fish of each age die off over time over the months and years after they recruit to the population), then use this model to predict the observed historical data (both within the most recent year and from past years), then use statistical estimation methods to find the population model parameters (recruitment and survival rates) that best agree with the data. So when such a method is "looking" at the 2001 data, it is using calculations of the 2001 population structure (numbers of fish of various ages) that are based in part on observations of those fish made in earlier years when the fish were younger. Any such approach requires a key assumption, namely that the survival rates of fish from year to year are at least somewhat predictable. Part of the model development and testing process is to search for indications about whether such assumptions have been violated (we do see some indications that survival rates of age 3 and older chub have varied over time, and there is consistent, strong variation in survival rate with age of fish—older fish appear to have consistently higher annual survival rates).

One way to think about the integrated assessment methods is that they produce point estimates for each year of population trend, as we could obtain from fitting a line through independent annual population estimates. But, the points along the assessment model trend line are calculated from population dynamics accounting relationships (recruitment and survival) rather than just some trend formula that is "unconstrained" by any knowledge of ecological relationships that have given rise to the trend. Further, the assessment model trend estimate for each year consists of both fish that were seen (tagged) in earlier years (and are likely to have survived to the year in question), and fish that were first seen in later years, but at sizes and ages implying that they must have been present in that year. That is, the assessment model trend estimates use sampling information both forward and backward in time, and thus should be most accurate for years (mid 1990s) where there are many surrounding observations. Conversely, they are least accurate for the most recent year(s), particularly for younger (recruiting) fish, about which we have the fewest direct observations.

Integrated assessment methods involve first constructing a population accounting model, to produce a table of predicted numbers of fish at age (or size) over time given input estimates of initial age structure, recruitments, and age-time survival patterns. These predicted numbers are then compared to observed capture and recapture patterns, using statistical measures called “likelihood functions” that estimate the odds of obtaining the data if the population model estimates were correct. Then the model estimates are systematically varied (using computer search routines) to seek the “maximum likelihood” estimates. There are two basic ways to carry out the population accounting calculations, called “stock synthesis” and “virtual population analysis”.

In the stock synthesis approach, the numbers of fish of each age present in 1989 and each cohort of young fish recruited since 1989 is treated as a separate unknown, and population structure is calculated forward in time from these starting numbers. This is what we did with “Supertag”, and to reduce the number of unknowns we assumed the population to have a stable age structure in 1989. We did not notice that the size-age data available for the early 1990s contain a much larger “bulge” of older fish than would a stable age distribution, and we now interpret that bulge as indicative of considerably higher recruitments during the 1970s-80s than in more recent years.

In the virtual population analysis approach, we simply reverse the population accounting calculations. We initialize the accounting calculations with estimates of numbers of fish at age in the most recent year, and we back-calculate how many additional fish must have been present in earlier years (and ages) in order to account for numbers of fish tagged and recaptured over time while allowing for natural mortality along the way. We believe that this approach gives a much better estimate of the population age structure in 1989, from which we can make inferences about how much higher recruitments must have been prior to 1989 in order to have produced that initial age structure. This approach has been implemented in a relatively simple (annual data only) way in a spreadsheet model called “Tagage” or “ Annual -ASMR”, and we are currently developing a much more detailed implementation that will make better use of within-year information (e.g. within-year mark-recapture observations; Monthly - ASMR) to improve the estimates of both long-term recruitment trend and of the most recent population size.

In Grand Canyon adaptive management, a really key issue is whether various management policies can improve humpback chub juvenile survival and recruitment. Integrated stock assessment methods are particularly critical for recruitment assessments. Our first real chance to look quantitatively at the abundance of each year class or cohort of chubs as it recruits, is in the late fall of the year after that cohort has hatched (as “age 2” fish), when many of the fish have reached the 150mm body length at which we think it is safe to tag them with PIT tags. In the last few years, fall mark-recapture programs in the Little Colorado River have started to give us such early point estimates of recruitment, but these estimates are quite unreliable (unknown and variable proportion of each cohort large enough to tag, unknown proportions of fish attempting to rear in mainstem vs LCR, relatively low numbers of fish captured and recaptured). If such noisy early estimates were our only recruitment "indices", we would have really serious trouble interpreting the results of any experiment aimed at improving recruitment (e.g. exotic fish removal). But with stock assessment models, we can integrate these early estimates with data collected in subsequent years as the fish grow and become fully vulnerable to tagging (and other indexing methods). This integration still requires assumptions about stability of survival rates (otherwise when we first see some of the recruits from a given cohort as 3-yr olds, 4-yr olds, etc. we would have no way to estimate how many additional young fish must have been present earlier in order to have produced these survivors).

Stock assessment data analysis should be viewed to some degree as a problem in risk management, where we must tradeoff between using noisy point sample (short-term mark-recapture and catch per effort index) information, versus using more complex methods built around assumptions (particularly about stability of survival rates over time) that cannot be fully tested with the available historical data. We can demonstrate that assessments of population trend (but not current abundance) are highly robust to such assumptions (we get about the same downward trend pattern for every survival assumption that we have thought to test so far). Furthermore this downward trend suggested by the stock assessment models is also indicated by independent catch rate data (a measure of relative abundance) in the LCR. However, this does not mean that we have obtained the "correct" answer to date. In short, there is no fundamentally "right" or "wrong" methodology, and no single "best" estimate of stock status and trend.

There has been some demand by Grand Canyon stakeholders to "give us a number" representing scientific consensus about the best assessment methodology and best point estimate of current chub stock size. Such demands are common in fisheries assessment and management situations in general, and represent a fundamental misunderstanding (or deliberate misrepresentation) about what scientists can and should provide. What we can provide is a set of probability distributions for stock size and trend, based on alternative assumptions about the data.

Scientists cannot, and should not, be expected to agree upon how to deal with the risk management problem of which assumptions to "trust", and for us to pretend such consensus might exist would be dishonest and misleading. Moreover, it is not a requirement or even a real need for effective policy design that we do produce a particular number or estimate. Perfectly reasonable judgments about management can be made on the basis of probabilistic assessments and statements about relative likelihood of various outcomes, just as humans must do in practically all decision situations that involve substantial public and private investments. To demand a single number from scientists is as unrealistic as it would be for a stock market investor to demand a single earnings number from a stock broker.

Probably the most important judgment call that needs to be made soon in relation to humpback chub is whether to abandon planned testing of various simple options for improving juvenile survival, in favor of treating the evidence of recent spawning stock decline as an "emergency" warranting simultaneous application of a whole suite of mitigation measures (TCD, hatchery supplementation, etc.). Straight-line extrapolation of the recent trend estimates would imply a significant risk of extinction for the LCR spawning population within the next 10-15 years. However, this prediction is not supported by estimates of recruitment rates of 2-year old fish.

Those rates appear to have been relatively stable since the early 1990s, though at considerably lower levels than would be needed to maintain the spawning population at 1989 levels. If recruitments continue to be stable, we predict that the spawning population will soon stop declining, and will stabilize at an average spawning abundance of roughly 75% of its current level, and that average will most likely be between 1000 and 2500 fish. That is, the assessment data do not in fact support demands for emergency policy actions. In terms of present, (and almost certainly continuing) uncertainty about the stock size estimates, it is hard to imagine picking a worse target or goal to try to confirm or deny than the current recovery goal of 2000 fish. Given existing investments in stock assessment data gathering, there is almost no chance that we will be able to say confidently whether or not this goal has been exceeded over the next decade, unless there is some really dramatic and obvious change in recruitment rate.

So what should be done…..?

Stay the present course of experimental actions using reasoned responses and treatments to inform future decisions. Be active about policy experimentation to promote learning and reduce uncertainty while simultaneously developing contingency plans for ‘emergency ‘ actions. Then use this toolbox of actions as an attempt to thwart extinction of this population in the next few years if further decline and lack of stability in the population becomes more apparent. A number of these actions, e.g. rearing young of the year fish in a hatchery or in another tributary as a refugia population, could be implemented sooner rather than later without materially affecting our ability to ‘learn’ about responses to management actions.

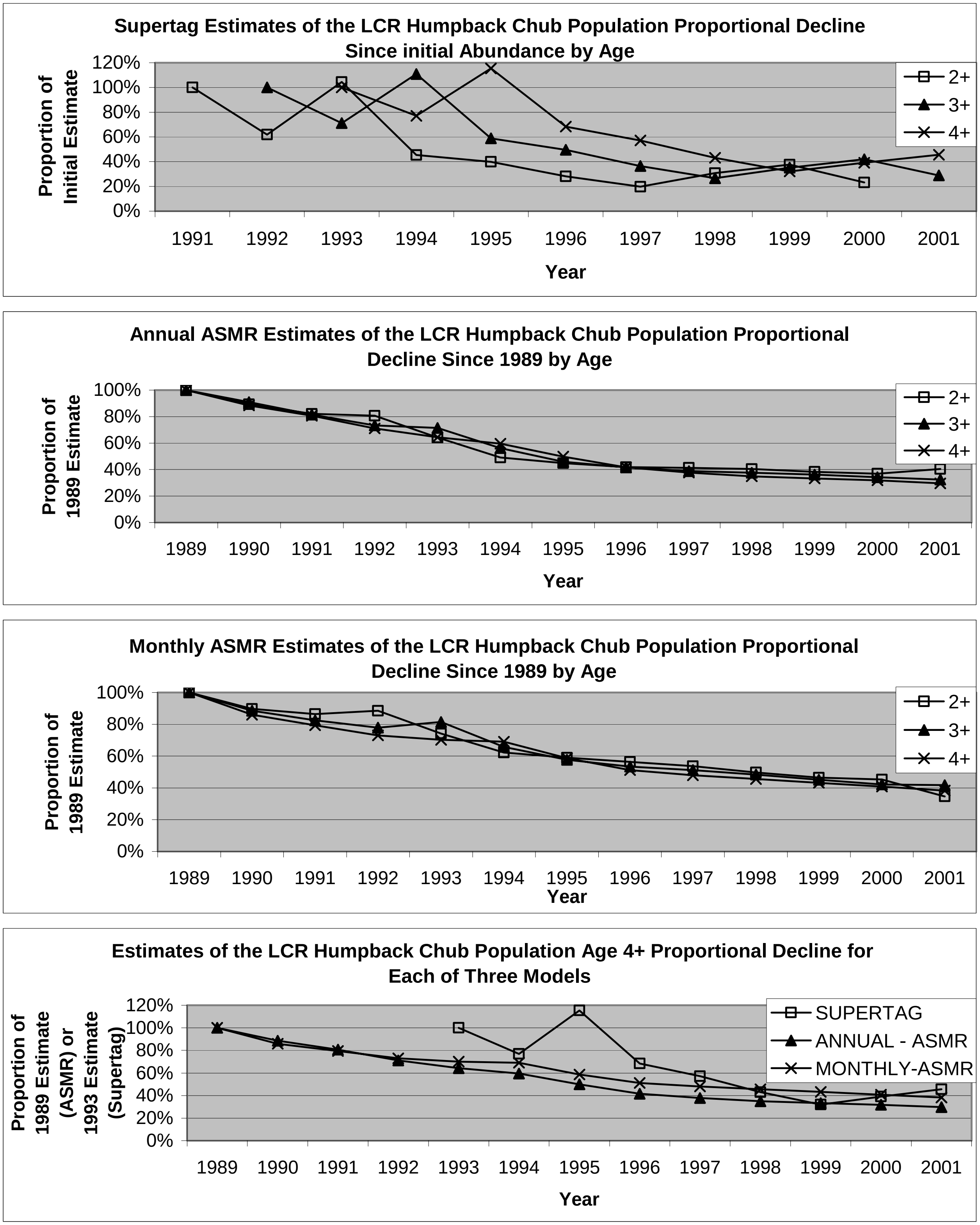

Supertag Estimates of the LCR Humpback Chub Population Proportional Decline Since initial Abundance by Age
Proportion of Initial Estimate
120%
100%
80%
60%
40%
20%
0%
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
2+
3+
4+
Annual ASMR Estimates of the LCR Humpback Chub Population Proportional Decline Since 1989 by Age
Proportion of 1989 Estimate
100%
80%
60%
40%
20%
0%
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
2+
3+
4+
Monthly ASMR Estimates of the LCR Humpback Chub Population Proportional Decline Since 1989 by Age
Proportion of 1989 Estimate
100%
80%
60%
40%
20%
0%
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
2+
3+
4+
Estimates of the LCR Humpback Chub Population Age 4+ Proportional Decline for Each of Three Models
Proportion of 1989 Estimate (ASMR) or 1993 Estimate (Supertag)
120%
100%
80%
60%
40%
20%
0%
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
SUPERTAG
ANNUAL - ASMR
MONTHLY-ASMR

Figure 1

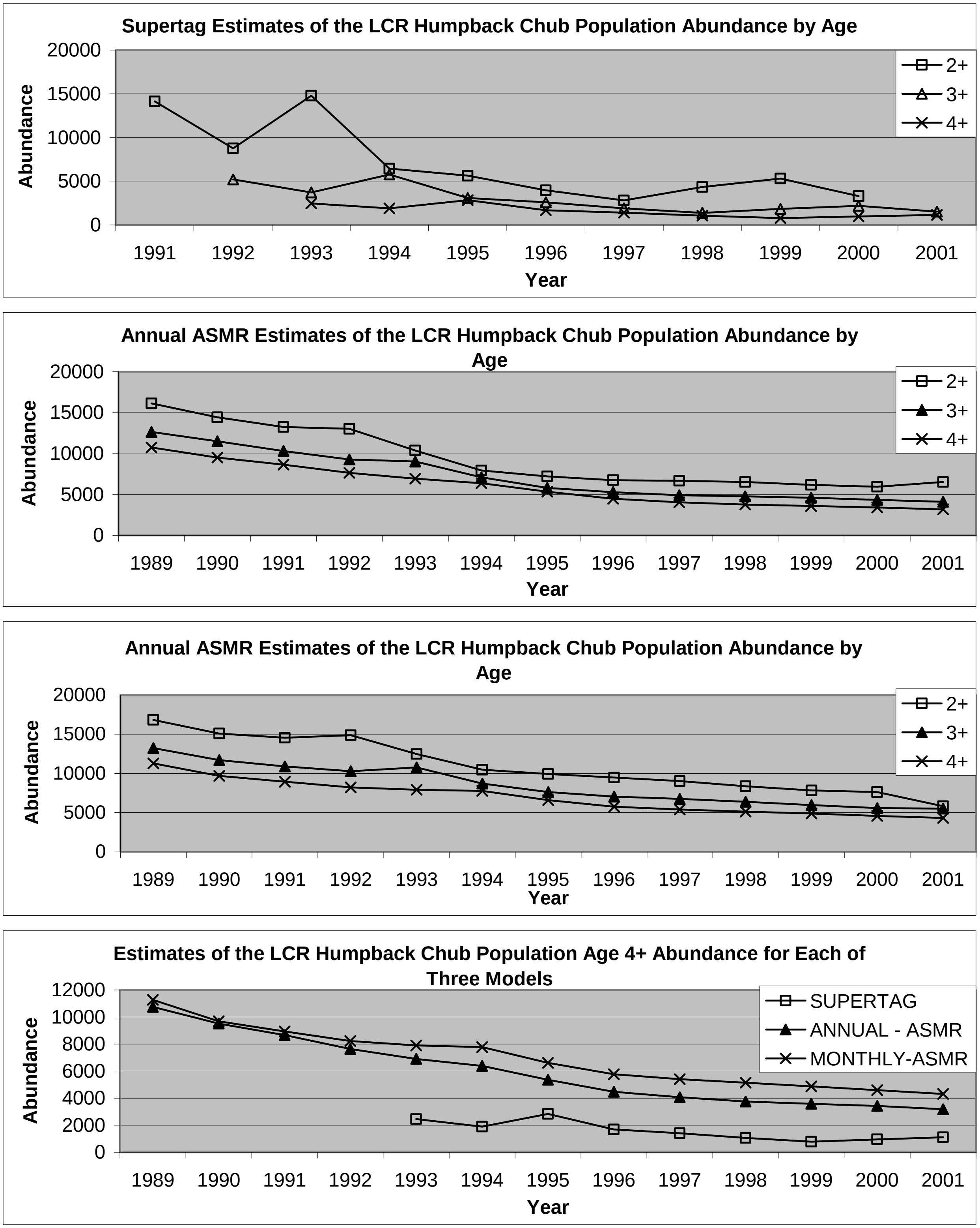
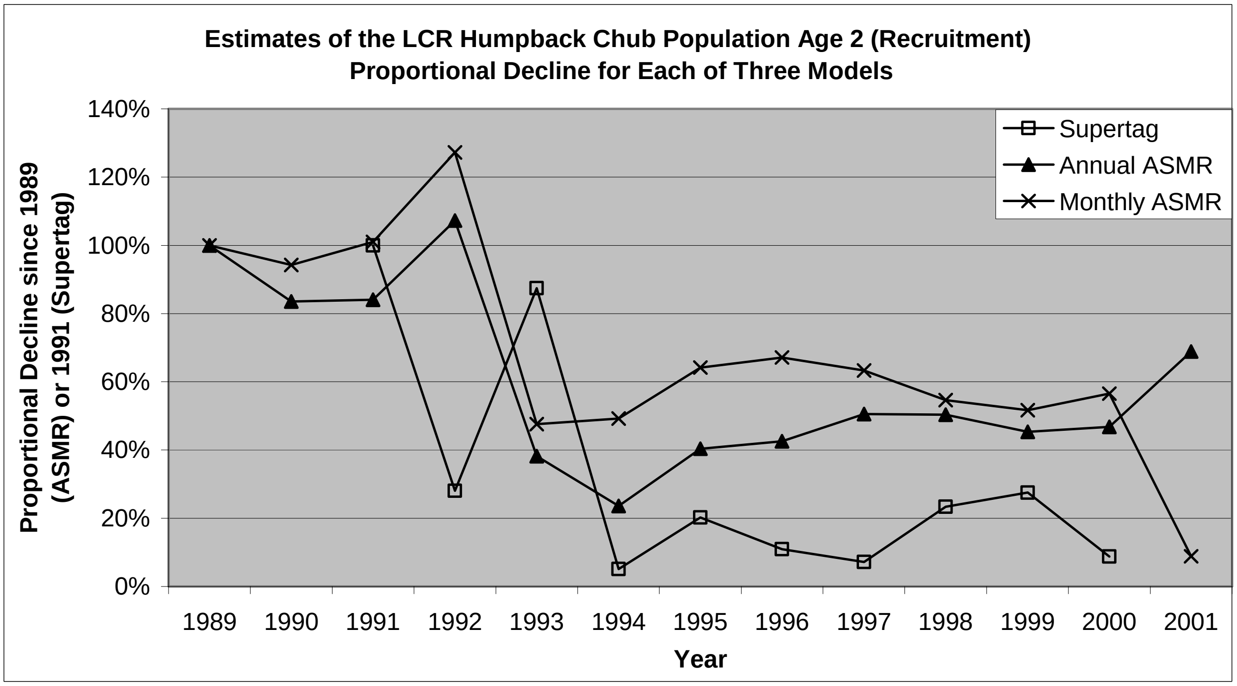

Supertag Estimates of the LCR Humpback Chub Population Abundance by Age
Abundance
20000
15000
10000
5000
0
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
2+
3+
4+
Annual ASMR Estimates of the LCR Humpback Chub Population Abundance by Age
Abundance
20000
15000
10000
5000
0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
2+
3+
4+
Annual ASMR Estimates of the LCR Humpback Chub Population Abundance by Age
Abundance
20000
15000
10000
5000
0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
2+
3+
4+
Estimates of the LCR Humpback Chub Population Age 4+ Abundance for Each of Three Models
Abundance
12000
10000
8000
6000
4000
2000
0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
SUPERTAG
ANNUAL - ASMR
MONTHLY-ASMR

Figure 2


Estimates of the LCR Humpback Chub Population Age 2 (Recruitment)
Proportional Decline for Each of Three Models
Proportional Decline since 1989 (ASMR) or 1991 (Supertag)
0%
20%
40%
60%
80%
100%
120%
140%
Supertag
Annual ASMR
Monthly ASMR
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

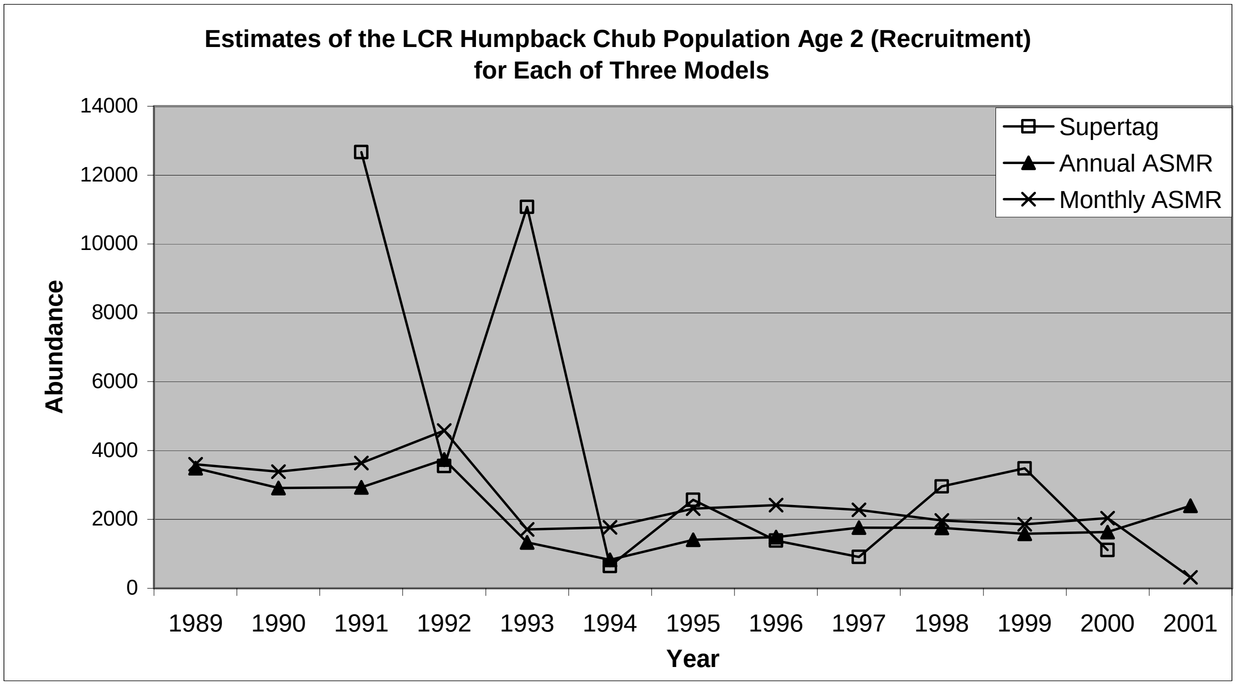

Estimates of the LCR Humpback Chub Population Age 2 (Recruitment)
for Each of Three Models
Abundance
0
2000
4000
6000
8000
10000
12000
14000
Supertag
Annual ASMR
Monthly ASMR
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year

Figure 3

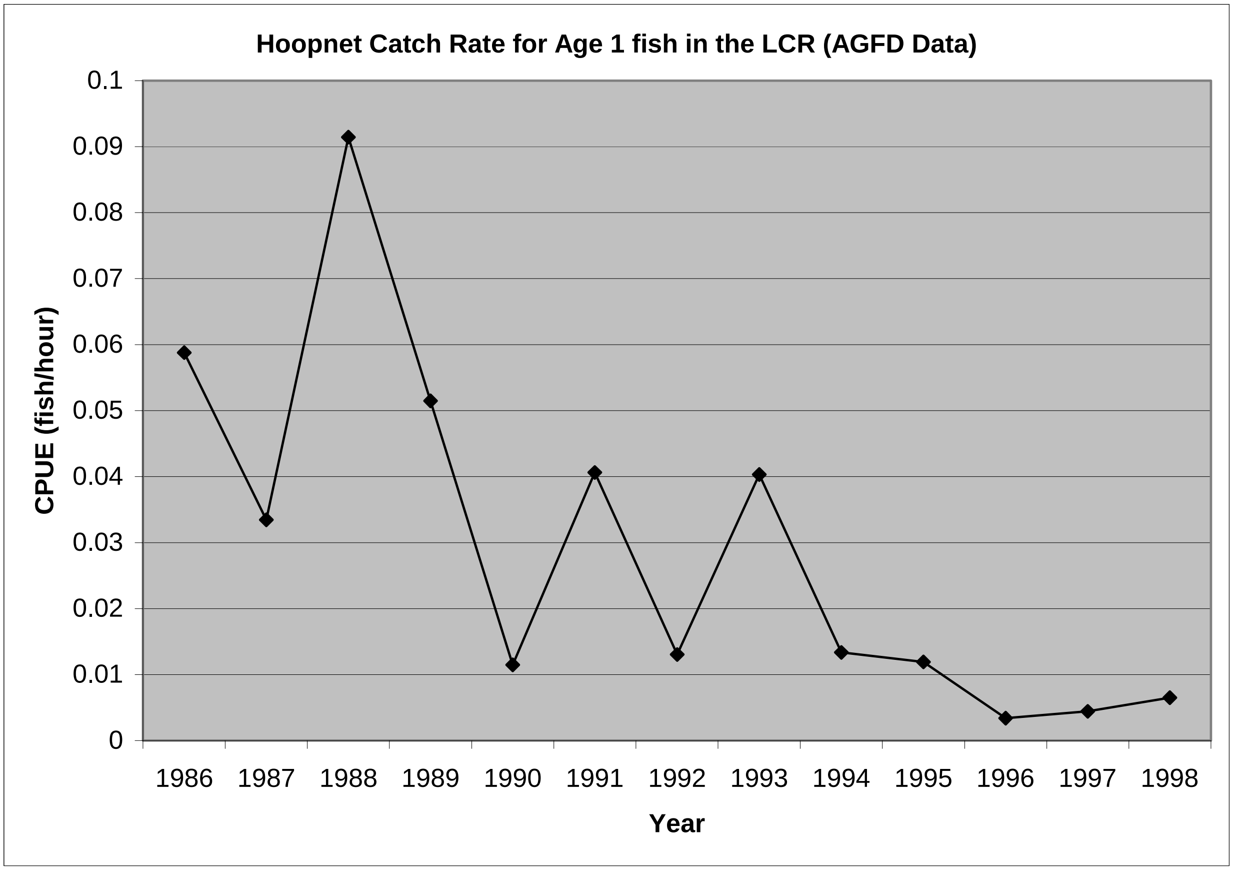

Hoopnet Catch Rate for Age 1 fish in the LCR (AGFD Data)
CPUE (fish/hour)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Year

Figure 4

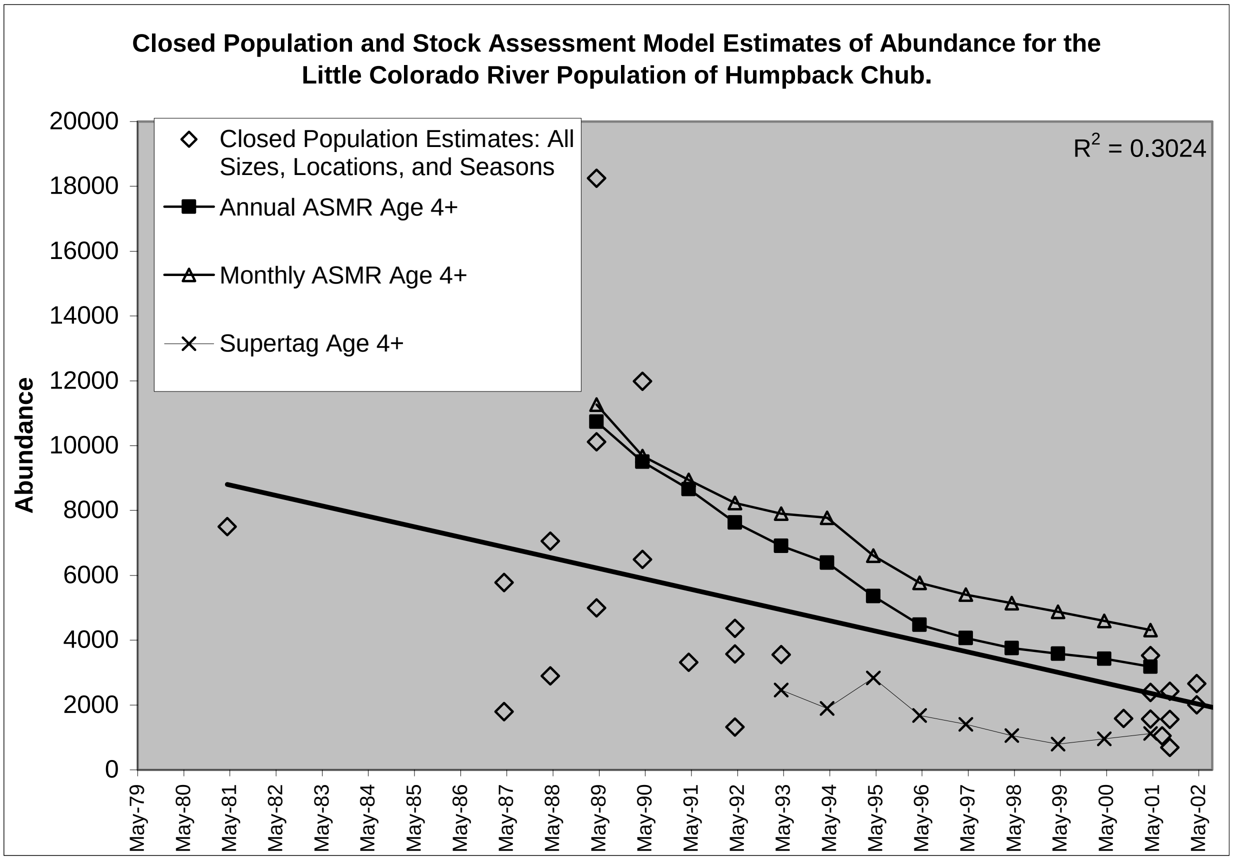


Figure 5

The sources and “quality” of closed population estimates plotted in Figure 5 are described in Table 1. This table is followed Figures 6-11, which depict the poulation trend using all or selected combinations of these point estimate data.

Table 1. Summary of closed population abundance estimates for the Little Colorado River population of humpback chub.

AUTHOR	LOCATION	DATE	FISH SIZE	ABUNDANCE ESTIMATE	METHOD	COMMENTS
Kaeding and Zimmerman 1982	LCR Inflow[a] and LCR.	1980-1981	>200 mm	7,000-8,000	Schnabel, Modified Schnabel, and Schumacher/Eschmeyer	Authors claim this is a "ballpark" estimate due to assumption violations.
Minckley 1988	LCR confluence (<1.2 km)	May 1987	>120 mm	5,783	Petersen	Invalid sample design; no distinction between mark and recapture efforts
Kubly 1990	LCR confluence (<1.2 km)	May 1987	>140 mm	1,800	Schnabel	Author states estimate is biased and precision is poor.
Minckley 1988	LCR confluence (<1.2 km)	May 1988	>120 mm	7,060	Petersen	Invalid sample design; no distinction between mark and recapture efforts
Kubly 1990	LCR confluence (<1.2 km)	May 1988	>140 mm	2,900	Schnabel	Author states estimate is biased and precision is poor.
Minckley 1989	LCR (<15 km)	May 1989	>150 mm	18,253	Petersen	Invalid sample design; no distinction between mark and recapture efforts.
Kubly 1990	LCR (<15 km)	May 1989	>140 mm	5,500-25,000 (estimate stabilized near 5,000 fish)	Schnabel	Author states estimate is biased and precision is poor.
Minckley 1989	LCR confluence (<1.2 km)	May 1989	>150 mm	10,120	Petersen	Invalid sample design; no distinction between mark and recapture efforts.

[a] Kaeding and Zimmerman defined the LCR Inflow Reach as Colorado River miles ~51.5-71.5
[b] Valdez and Ryel 1995 defined the LCR Inflow Reach as Colorado River miles 57-65.4
[c] Trammell and Valdez 2002 defined the LCR Inflow Reach as Colorado River miles 56.3-68.3

Table 1. Summary of closed population abundance estimates for the Little Colorado River population of humpback chub (continued).

AUTHOR	**LOCATION**	**DATE**	**FISH SIZE**	**ABUNDANCE ESTIMATE**	**METHOD**	**COMMENTS**
Minckley 1990	LCR confluence (<1.2 km)	May 1990	>150 mm	6,492	Petersen	Invalid sample design; no distinction between mark and recapture efforts.
Minckley 1990	LCR (<15 km)	May 1990	>150 mm	11,985	Petersen	Invalid sample design; no distinction between mark and recapture efforts.
Douglas and Marsh 1996	LCR confluence (<1.2 km)	May 1992	>150 mm	1,320	Program CAPTURE (many estimators used; statistically determined the best one)	Appears sound; peer-reviewed journal publication.
Douglas and Marsh 1996	LCR (<15 km)	May 1992	>150 mm	4,363	Program CAPTURE (many estimators used; statistically determined the best one)	Appears sound; peer-reviewed journal publication.
Valdez and Ryel 1995	LCR Inflow[b]	1991	>200 mm	3,315	Program CAPTURE (many estimators used; statistically determined the best one)	Appears sound; peer-reviewed contractor report.
Valdez and Ryel 1995	LCR Inflow[b]	1992	>200 mm	3,572	Program CAPTURE (many estimators used; statistically determined the best one)	Appears sound; peer-reviewed contractor report.
Valdez and Ryel 1995	LCR Inflow[b]	1993	>200 mm	3,558	Program CAPTURE (many estimators used; statistically determined the best one)	Appears sound; peer-reviewed contractor report.
Coggins and Van Haverbeke 2001	LCR (< 14.2 km)	Oct. 2000	> 135 mm	1,590	Chapman-Petersen	Appears sound; peer-reviewed agency report.
Van Haverbeke and Coggins 2003	LCR (< 14.2 km)	May 2001	>100 mm	3,527	Length – Stratified Chapman-Petersen	Appears sound; peer-reviewed agency report.
Van Haverbeke and Coggins 2003	LCR (< 14.2 km)	May 2001	>150 mm	2,387	Length – Stratified Chapman-Petersen	Appears sound; peer-reviewed agency report.
Van Haverbeke and Coggins 2003	LCR (< 14.2 km)	May 2001	>200 mm	1,568	Length – Stratified Chapman-Petersen	Appears sound; peer-reviewed agency report.

[a] Kaeding and Zimmerman defined the LCR Inflow Reach as Colorado River miles ~51.5-71.5
[b] Valdez and Ryel 1995 defined the LCR Inflow Reach as Colorado River miles 57-65.4
[c] Trammell and Valdez 2002 defined the LCR Inflow Reach as Colorado River miles 56.3-68.3

Table 1. Summary of closed population abundance estimates for the Little Colorado River population of humpback chub (continued).

AUTHOR	LOCATION	DATE	FISH SIZE	ABUNDANCE ESTIMATE	METHOD	COMMENTS
Trammell and Valdez 2002	LCR Inflow [c]	August 2001	>200 mm	1,044	Chapman-Petersen	Appears sound; peer-reviewed contractor report
Van Haverbeke and Coggins 2003	LCR (< 14.2 km)	Oct. 2001	>100 mm	2,424	Length – Stratified Chapman-Petersen	Appears sound; peer-reviewed agency report.
Van Haverbeke and Coggins 2003	LCR (< 14.2 km)	Oct. 2001	>150 mm	1,555	Length – Stratified Chapman-Petersen	Appears sound; peer-reviewed agency report.
Van Haverbeke and Coggins 2003	LCR (< 14.2 km)	Oct. 2001	>200 mm	695	Length – Stratified Chapman-Petersen	Appears sound; peer-reviewed agency report.
Van Haverbeke *In Review*	LCR (< 14.2 km)	May 2002	>150 mm	2,666	Length – Stratified Chapman-Petersen	Author suggests estimate may contain positive bias.
Van Haverbeke *In Review*	LCR (< 14.2 km)	May 2002	>200 mm	2,002	Length – Stratified Chapman-Petersen	Author suggests estimate may contain positive bias.
Van Haverbeke *In Review*	LCR (< 14.2 km)	Oct. 2002	>100 mm	4,777	Darroch and Length – Stratified Chapman-Petersen	Author suggests estimate is unbiased.
Van Haverbeke *In Review*	LCR (< 14.2 km)	Oct. 2002	>150 mm	2,774	Darroch	Author suggests estimate is unbiased.
Van Haverbeke *In Review*	LCR (< 14.2 km)	Oct. 2002	>200 mm	839	Darroch	Author suggests estimate is unbiased.

[a] Kaeding and Zimmerman defined the LCR Inflow Reach as Colorado River miles ~51.5-71.5
[b] Valdez and Ryel 1995 defined the LCR Inflow Reach as Colorado River miles 57-65.4
[c] Trammell and Valdez 2002 defined the LCR Inflow Reach as Colorado River miles 56.3-68.3

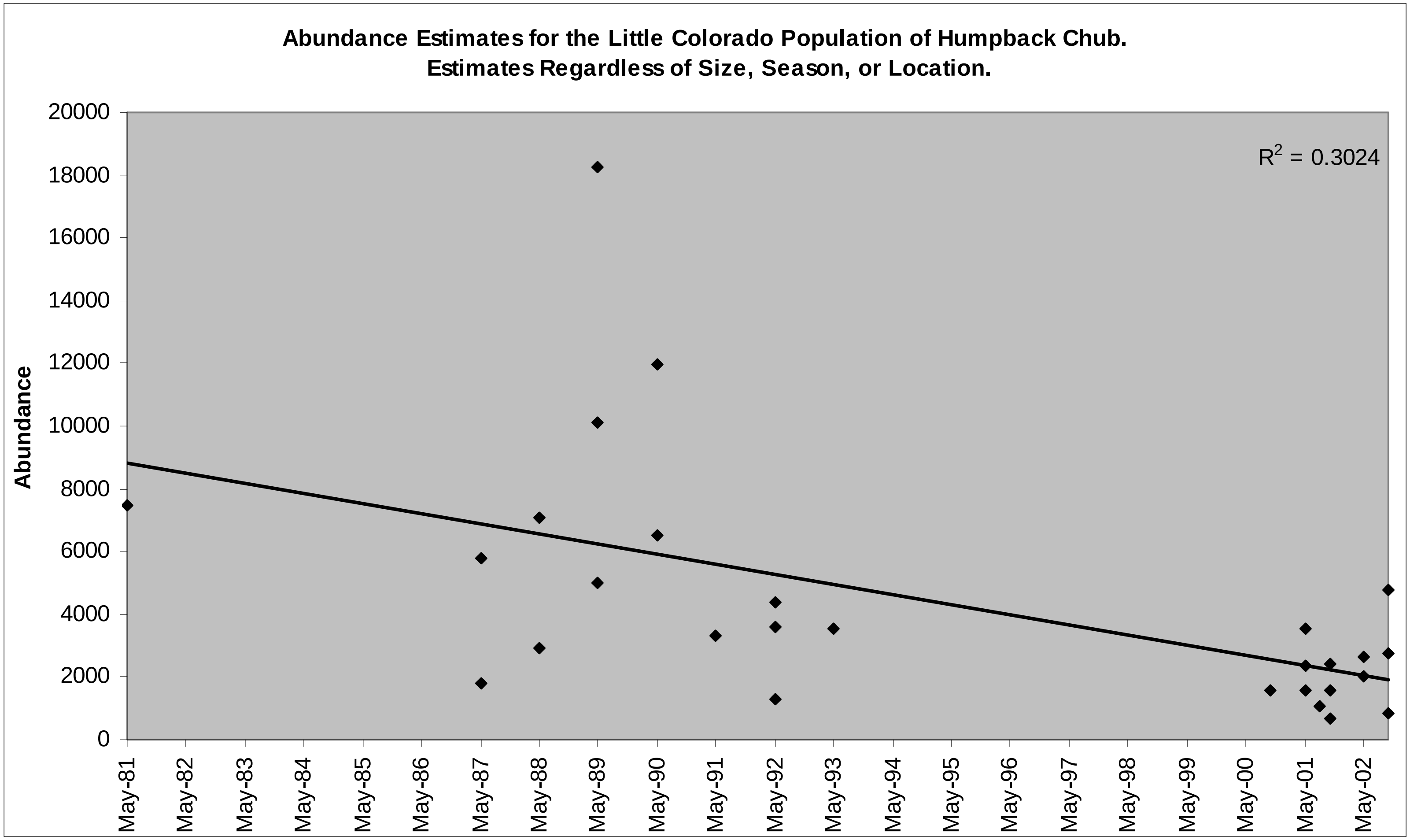

Abundance Estimates for the Little Colorado Population of Humpback Chub.
Estimates Regardless of Size, Season, or Location.
Abundance
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
$R^2 = 0.3024$
May-81
May-82
May-83
May-84
May-85
May-86
May-87
May-88
May-89
May-90
May-91
May-92
May-93
May-94
May-95
May-96
May-97
May-98
May-99
May-00
May-01
May-02

Figure 6

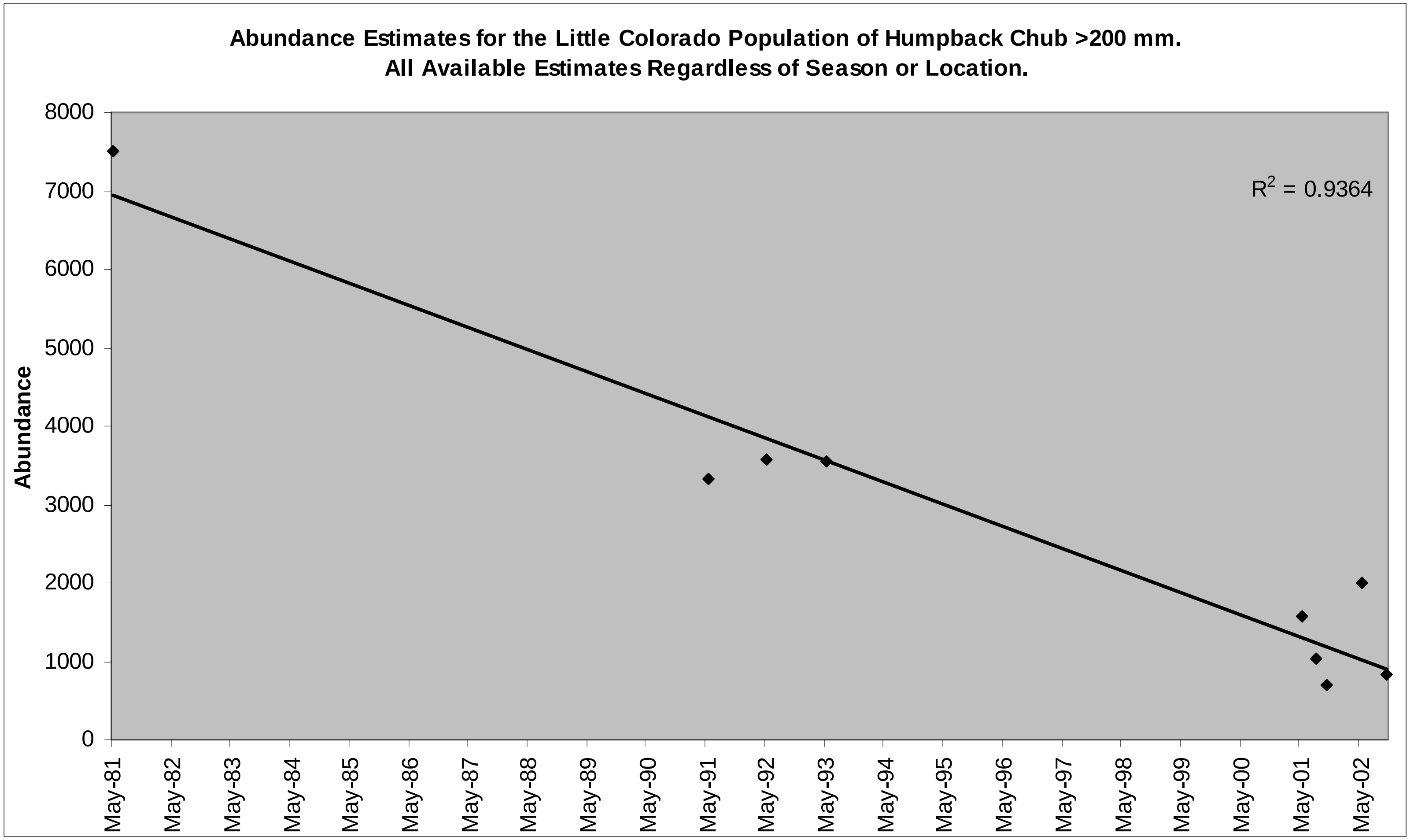

Abundance Estimates for the Little Colorado Population of Humpback Chub >200 mm.
All Available Estimates Regardless of Season or Location.
Abundance
8000
7000
6000
5000
4000
3000
2000
1000
0
R² = 0.9364
May-81
May-82
May-83
May-84
May-85
May-86
May-87
May-88
May-89
May-90
May-91
May-92
May-93
May-94
May-95
May-96
May-97
May-98
May-99
May-00
May-01
May-02

Figure 7

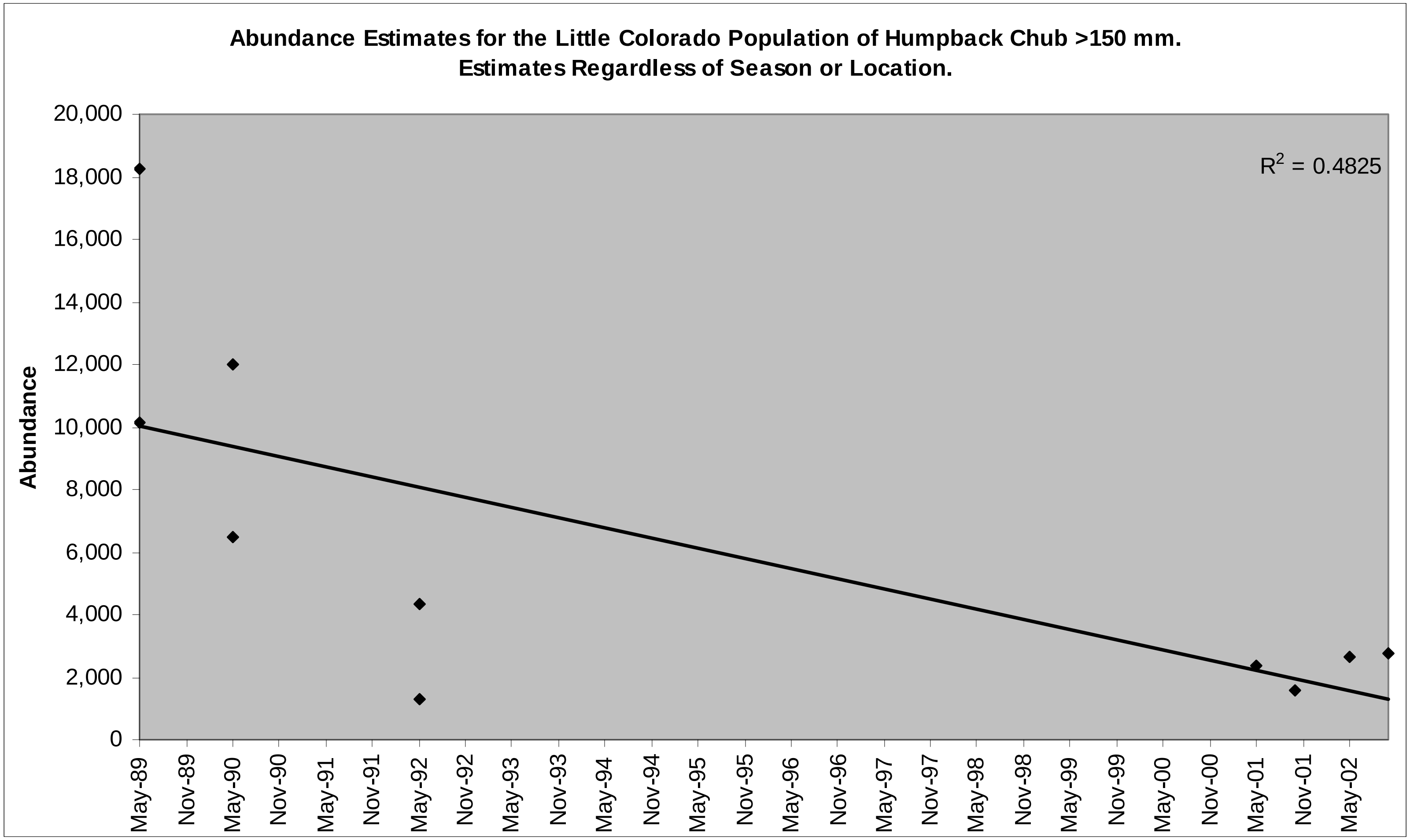

Abundance Estimates for the Little Colorado Population of Humpback Chub >150 mm.
Estimates Regardless of Season or Location.
Abundance
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
R2 = 0.4825
May-89
Nov-89
May-90
Nov-90
May-91
Nov-91
May-92
Nov-92
May-93
Nov-93
May-94
Nov-94
May-95
Nov-95
May-96
Nov-96
May-97
Nov-97
May-98
Nov-98
May-99
Nov-99
May-00
Nov-00
May-01
Nov-01
May-02

Figure 8

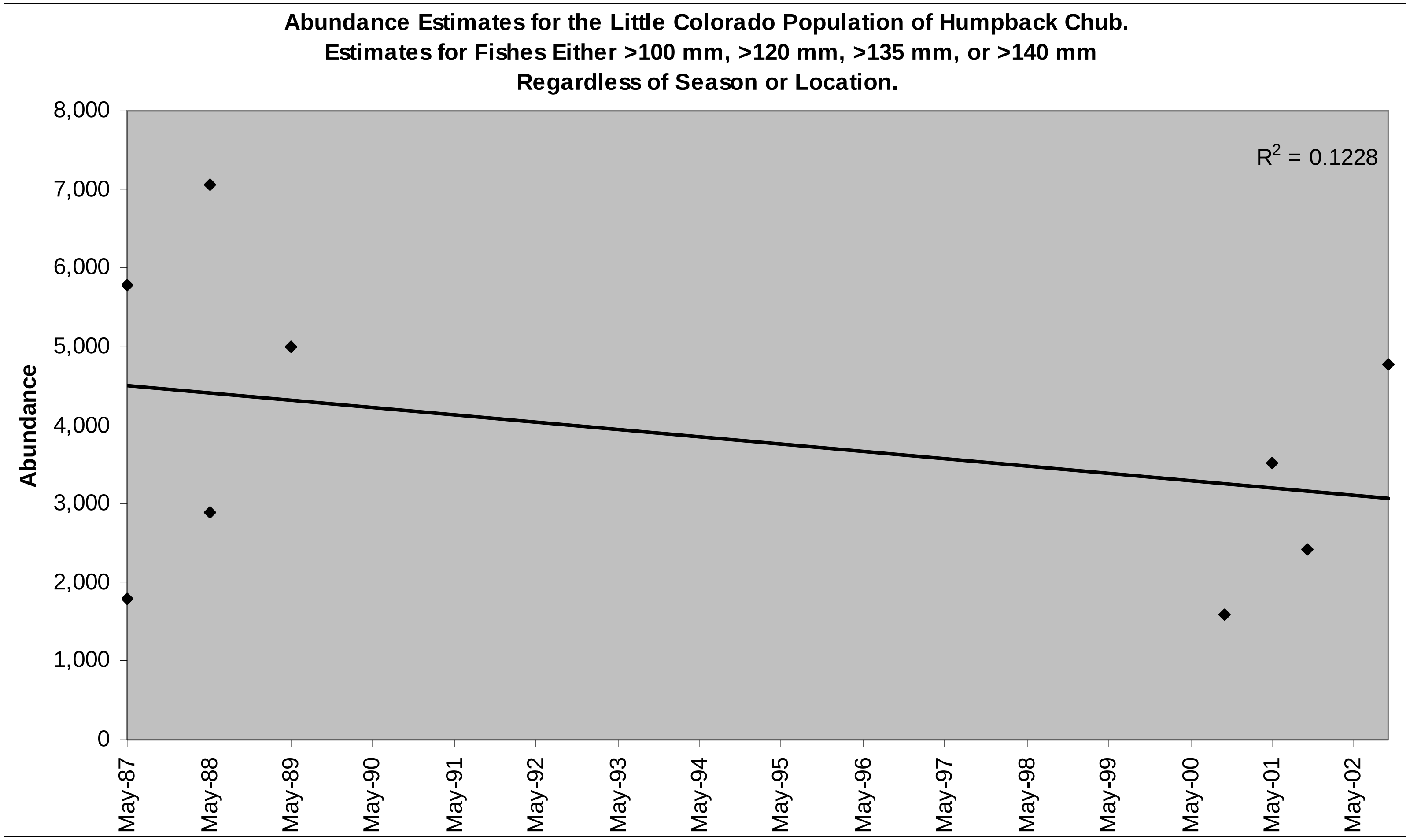

Abundance Estimates for the Little Colorado Population of Humpback Chub.
Estimates for Fishes Either >100 mm, >120 mm, >135 mm, or >140 mm
Regardless of Season or Location.
Abundance
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
R^2 = 0.1228
May-87
May-88
May-89
May-90
May-91
May-92
May-93
May-94
May-95
May-96
May-97
May-98
May-99
May-00
May-01
May-02

Figure 9

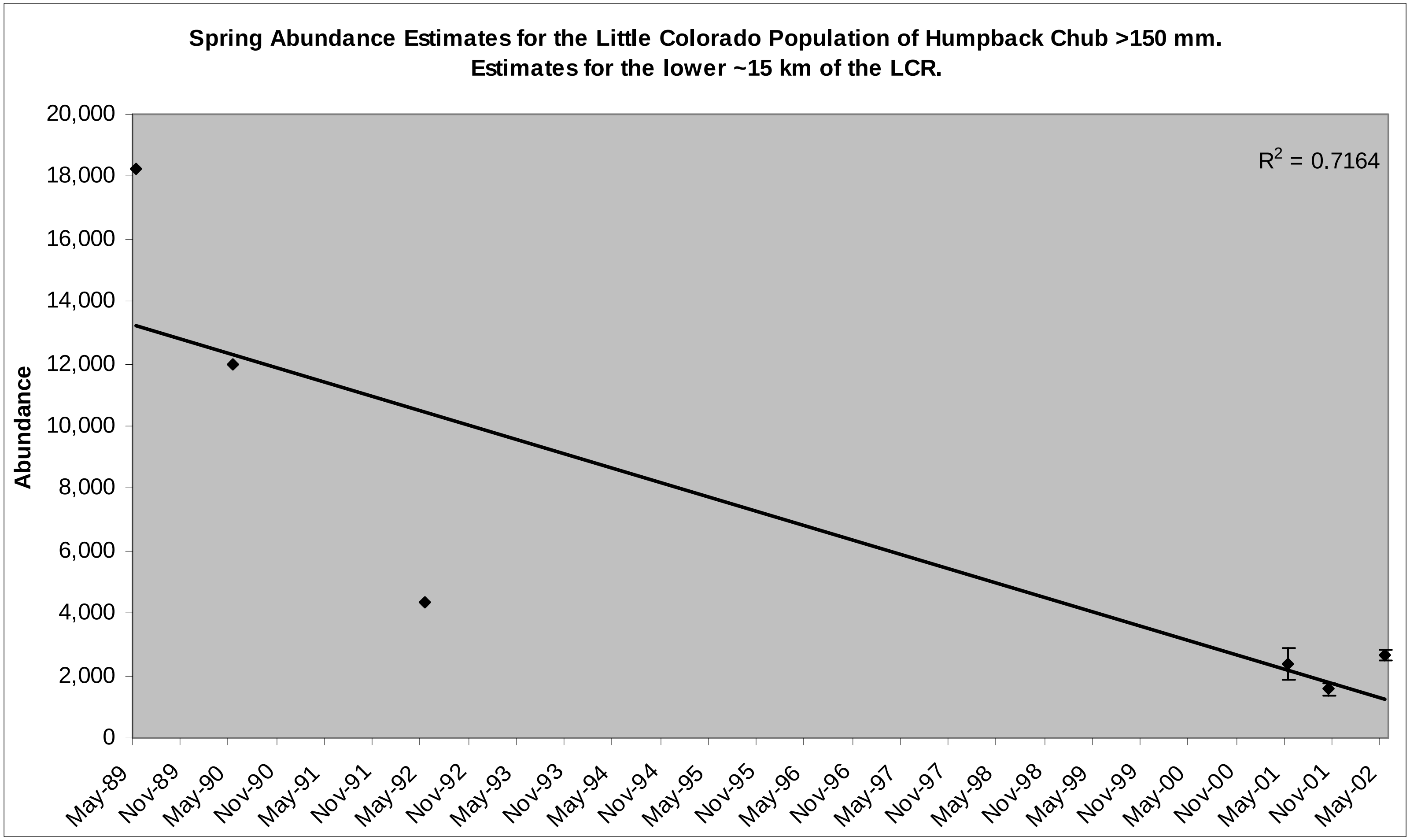

Spring Abundance Estimates for the Little Colorado Population of Humpback Chub >150 mm.
Estimates for the lower ~15 km of the LCR.
Abundance
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
R2 = 0.7164
May-89
Nov-89
May-90
Nov-90
May-91
Nov-91
May-92
Nov-92
May-93
Nov-93
May-94
Nov-94
May-95
Nov-95
May-96
Nov-96
May-97
Nov-97
May-98
Nov-98
May-99
Nov-99
May-00
Nov-00
May-01
Nov-01
May-02

Figure 10

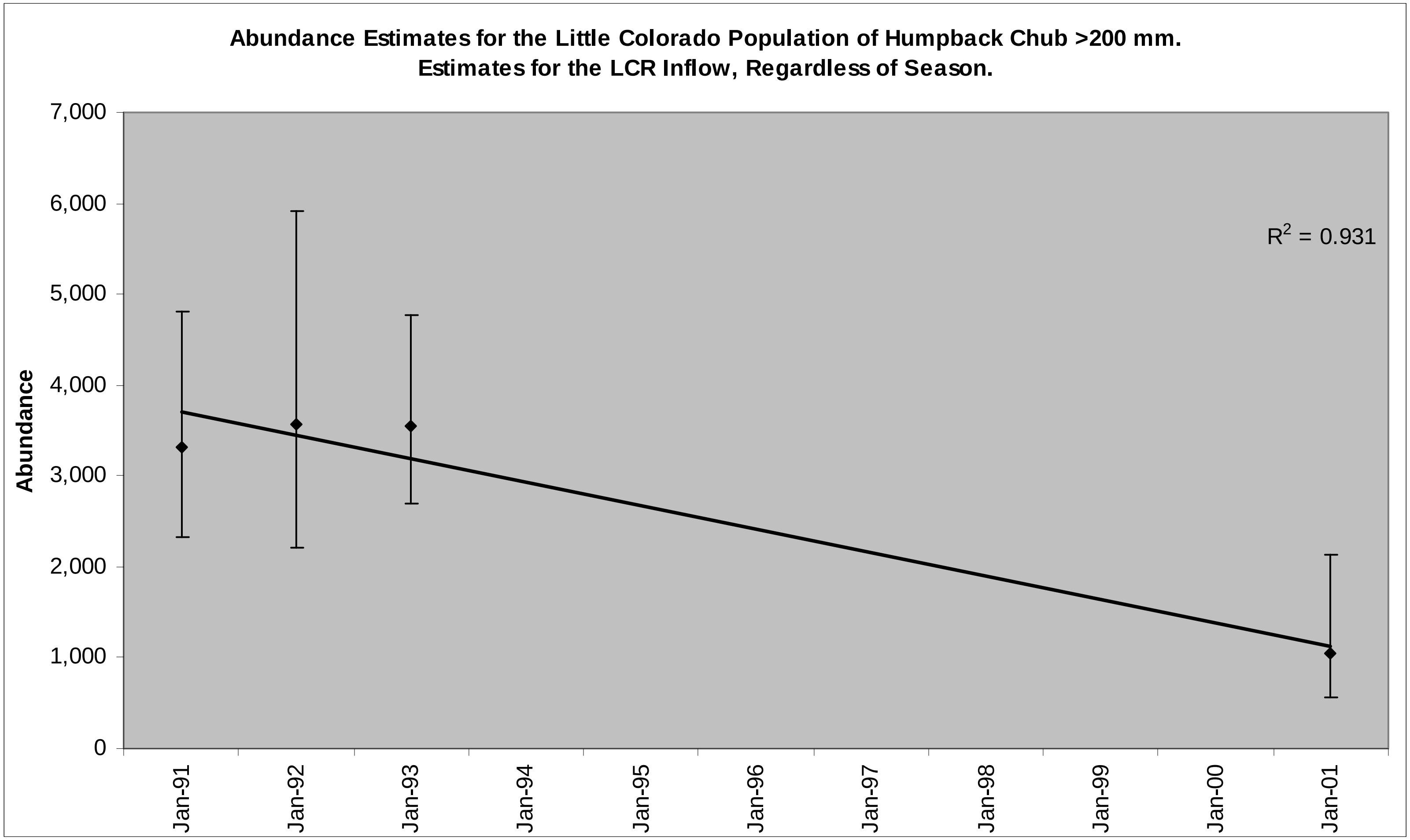

Abundance Estimates for the Little Colorado Population of Humpback Chub >200 mm.
Estimates for the LCR Inflow, Regardless of Season.
Abundance
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
R2 = 0.931
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Jan-01

Figure 11

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