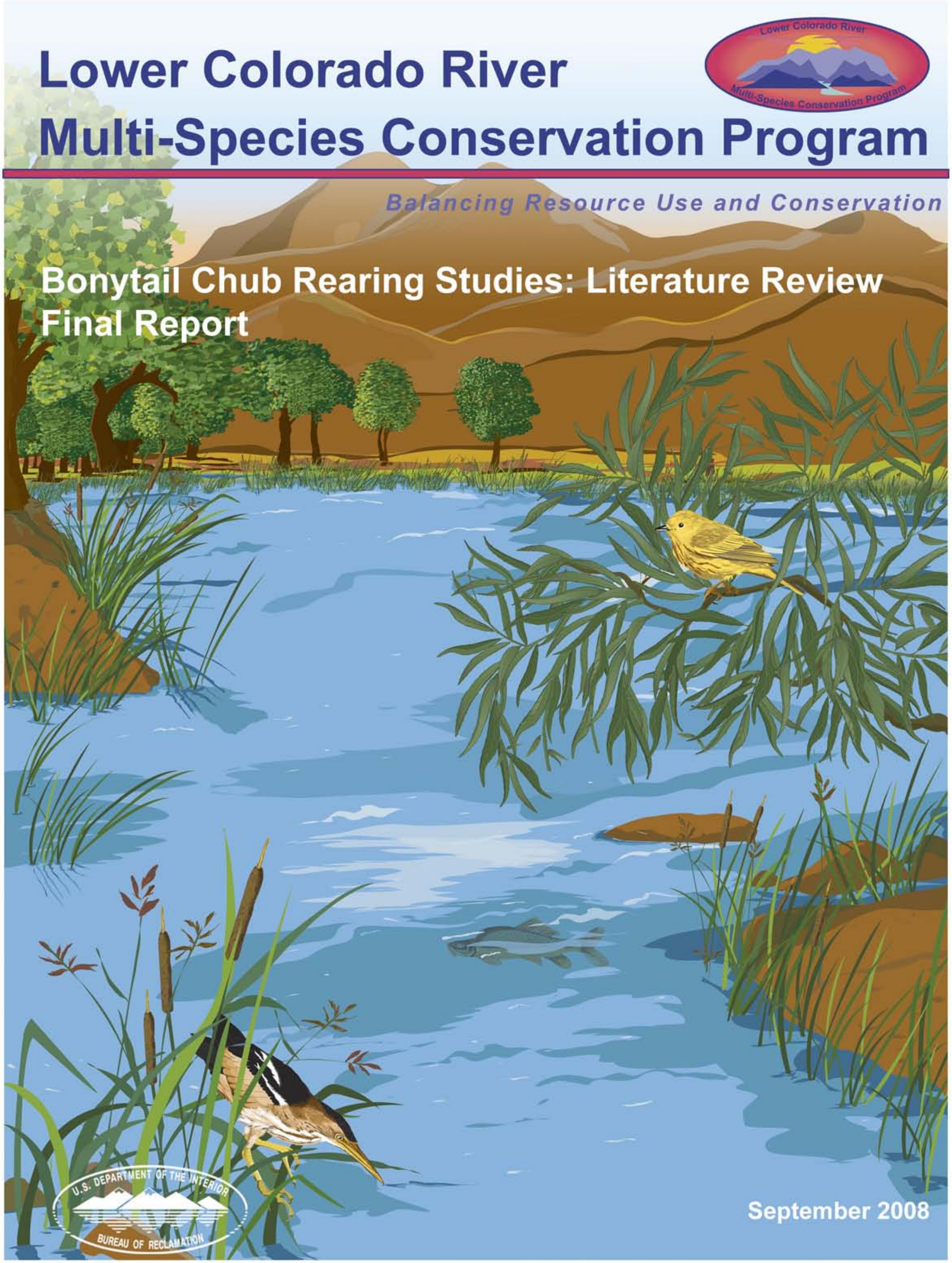
Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Bonytail Chub Rearing Studies: Literature Review
Final Report



September 2008

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Bonytail Chub Rearing Studies: Literature Review
Final Report

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Submitted under a Cooperative Ecosystems Study Unit agreement to the Bureau of Reclamation, Boulder City, Nevada

Lower Colorado River
Multi-Species Conservation Program
Bureau of Reclamation
Lower Colorado Region
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DISCLAIMER: The authors exercised reasonable care to ensure that the information presented in this report is correct and accurate; however, we cannot assume responsibility for omissions or inadvertent errors, and the user assumes all risks of use. We provided each site visit participant an opportunity to comment on results of their interview, but not everyone responded to requests for input so some results did not benefit from such review; these are identified as appropriate. Use of trade names does not constitute endorsement or recommendation for use by the authors or by the Bureau of Reclamation.

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SUMMARY

This report represents part of Work Task C11 of the Multi-Species Conservation Plan for the lower Colorado River. It presents the findings of a comprehensive literature review with focus on dynamics of captive rearing of endangered bonytail chub *Gila elegans* that dealt with hatchery programs in general and with variation in growth in particular. Also included are summaries of on-site interviews with hatchery professionals about their experience and programs. We attempted to identify practices and conditions that are associated with successful rearing events, and interpreted the results of these investigations to develop recommendations of specific areas of research or management that may be pursued to answer pertinent questions and enhance existing programs. Our ultimate goal was to identify and develop rearing strategies that minimize growth variation while accommodating efficient growth to target size (at least 30 cm), and thereby increase long-term, post-stocking survival of bonytail.

Results of the literature review and interview process led to development of a suite of recommendations that are summarized below. Implementation of these recommendations is expected to lead directly to opportunities to increase bonytail growth rates and the efficiency of bonytail grow-out. Some recommendations are generally applicable, while the suitability of others for application at any given facility or grow-out site should be evaluated individually by each responsible entity.

1. Perform dietary studies with various sizes of juvenile bonytail that includes feeding time, under pond conditions and with and without supplemental natural pond production.
2. Develop a specific diet for bonytail.
3. Classify and enumerate naturally produced invertebrate foods in ponds and raceways, and install “bug lights” over ponds.
4. Determine how feeding frequency and time of feeding affect growth. Add automatic feeders to facilities for crepuscular feedings.

5. Determine optimal feeding rate as percent body weight, and coincide these with feeding time experimentation.
6. Quantify “ad libitum” for larval and early juvenile culture.
7. Adjust the field-stocking month to within one month of hatchery spawning time to coincide with bonytail exhibiting their development of secondary sexual characteristics.
8. Under laboratory conditions, assess onset of sexual maturity as a function of temperature and age.
9. Sacrifice and necropsy a number of the slow growing bonytail per year class to determine gender.
10. Experiment with at least biannual size sorting and segregation of fast- and slow-growing fish.
11. Perform flow studies to determine if flow added to static and low flow ponds and raceways would increase energy expended, which could increase feeding and add growth.
12. Willow Beach NFH and Achii Hanyo Native FH should monitor fish growth regularly as these stations medically treat their fish.
13. Investigate whether constant light (24 h photoperiod) and/or dietary adjustments to reduce amounts of available energy for reproduction would reduce or eliminate volunteer reproduction.
14. Use standardized tracking sheets as a “chain of custody” to follow each year class of fish from spawning to stocking, and in between the many facilities that a single year class of fish may reside.
15. Designate two permanent repositories for all relevant Colorado River fish data, one for each upper and lower basin, and annually exchange data between basins so complete stocking records basin wide are available.

INTRODUCTION

Bonytail *Gila elegans* is one of the “big river” fishes that once was common and widely distributed throughout the Colorado River basin of western North American including parts of Arizona, California, Colorado, Nevada, Utah, and Wyoming in the United States, and onto the Colorado River delta in Baja California Norte and Sonora, Mexico. Wild bonytail populations likely numbered in the hundreds of thousands less than half a century ago, but those remaining today are so small that reliable abundance estimates cannot be developed. Water development, and introduction and establishment of non-native species resulted in widespread extirpation and declines in distribution and abundance of this and other native species beginning early in the 20th century, which culminated in listing as endangered (U.S. Fish & Wildlife Service [FWS] 1980). The species status has deteriorated to grave condition despite substantial restoration efforts, and bonytail is considered functionally extirpated in the wild -- there are no reproducing populations remaining.

As a functionally extirpated species, bonytail now occur in the Colorado River basin only as scattered repatriates and rare wild individuals in Lakes Havasu and Mohave, and as captive populations in isolated backwaters and constructed facilities. An ongoing stocking program throughout the upper and lower basins has thus far failed to establish new populations despite significant efforts over a period of many years by a suite of entities. An ambitious lower Colorado River (Lakes Havasu and Mohave) stocking program supported by hatchery propagation was initiated more than 25-years ago, but recaptures are few and long-term survival has been nil. Most early stockings were of small fish that apparently were lost to predation, but long-term survival has been disappointing even for larger fish stocked in recent years. There have been few adaptive adjustments to the program to incorporate new information, or attempts to increase survival of stocked fish. Similar results are noted with the upper basin program.

Bonytail stocking commitments vary by basin. For the lower basin, the U.S. Fish & Wildlife Service committed in their 1996 Biological Opinion to produce 25,000, 250-300 mm TL bonytail for stocking into Lake Mohave and 6,000 juvenile fish for stocking into Lake Havasu (Devine 1995; LitID[1] 1959). In addition, the Lower Colorado River Multi-Species Conservation Program has production goals of 620,000, 300 mm TL bonytail to be stocked over the next 50 years into Lake Mohave (5,000 fish/yr for 40 years), from Davis Dam to Parker Dam (4,000 fish/yr for 50 years, and between Parker and Imperial dams (8,000 fish/yr for five consecutive years and 4,000 fish/yr for 45 years) (Burke 2006; LitID 1953). In the upper basin, the State of Colorado is committed to the annual production of 24,000 fish, 200+ mm TL, and the State of Utah to annually produce 16,280 fish, 200+ mm TL for stocking into their respective portions of the Colorado River and its connectives (Czapla 2002; LitID 667).

It has been reliably determined that post-stocking survival of some hatchery-reared native Colorado River fishes is strongly correlated with size at release, with survivorship increasing dramatically within a relatively narrow interval of fish length (e.g., Marsh et al. 2003). Bonytail have been propagated and reared under hatchery conditions for several decades, and typically have exhibited exceptionally variable growth rates, even within a single cohort or year class. This wide-size variation within a group of fish is important because the largest individuals have the highest expectation of survival after release into the wild, yet their separation from smaller fish is problematic. Reasons for the phenomenon of variable growth are unknown but could include genetics, seasonal effects, diet, density, temperature, or other conditions of the rearing environment. Regardless, development of methods to reduce growth variations and to rear fish uniformly to substantial size (12-inches or 30-cm, or larger) has potential to increase both hatchery efficiency and post-stocking survival.

[1] A unique literature identification number (LitID) assigned to each piece of literature for tracking purposes (see below) are reported in text to assist in physical location by staff, and in data tables and appendices to simplify reporting.

It was the focus of this study to identify and review available literature and determine factors that can minimize variation in growth and contribute to efficient growth to attain larger size at stocking. We also attempted to identify specific areas for follow-up research and management investigation, and make management recommendations.

METHODS

Comprehensive Literature Review

Bonytail has been under hatchery propagation and rearing for more than 25 years and a wide variety of literature exists on past and on-going programs. This literature includes but is not limited to published papers and book chapters, agency and contractor reports, abstracts of presentations at formal and informal professional meetings, investigator notes, and other media. Generally, more recent, peer-reviewed research is more readily available than earlier documentation. For this report, we identified, located, acquired, reviewed, and critically interpreted as much of this literature as possible. We also examined relevant documents for closely related humpback chub *Gila cypha* in those instances where we believed that literature could contribute meaningful new information to our review and assessment of bonytail rearing.

We attempted to evaluate diverse aspects of culturing the species including brood stock acquisition and maintenance, parasites and disease, molecular genetics, artificial and volunteer propagation (i.e., fish spawning naturally), life-stage specific diet and feeding, growth, harvest and culling, handling, transport, and related material that dealt with wild fish. We initially reviewed the update of the “Bibliographies for Native Colorado Big River Fishes” (Marsh et al. 2005) and extracted target information by performing word queries on citation titles. The following suite of keywords was developed: acquisition, adult, artificial, bonytail, bonytail chub, brood, condition, culture, diet, disease, egg, feed, feeding, food, fry, genetic, genetics, growth, handling, harvest, hatchery, humpback, juvenile, larvae, larva, larval, life, life stage, maintenance, parasite, pond, procedure, propagation, quality, rear, rearing, spawning, stock, survival, temperature, transport, water quality, and young. Relevant citations thus identified were exported into a Microsoft ® Office Access (hereafter, Access) database table we titled “Bibliography.” To this table, we added additional material after searching through internet/web based sources, academic and institutional libraries, state and federal agencies, and personal contacts. A unique literature identification number (LitID) was assigned to each piece of literature for tracking purposes. We then attempted to locate and acquire each document from appropriate sources (e.g., author, agency, library, repository, or private collection) and once in-hand, we made physical paper copies and organized them by LitID.

Some literature not available for any of a variety of reasons could not be evaluated, and these are identified in Appendix 1. In the event an ambitious reader wishes to pursue an independent attempt to obtain those documents and is successful, we request the recipient share a copy with us for inclusion in any future work.

Site Visits

We identified facilities that currently have bonytail on station. These included four federal facilities: Dexter National Fish Hatchery & Technology Center (Dexter NFH & TC), Dexter, NM; Willow Beach National Fish Hatchery (Willow Beach NFH), Willow Beach, AZ; Uvalde National Fish Hatchery (Uvalde NFH), Uvalde, TX; and Achii Hanyo Native Fish Hatchery (Achii Hanyo Native FH), near Poston, AZ; and two state facilities: Wahweap State Fish Hatchery (Wahweap SFH), Big Water, UT and John W. Mumma Native Aquatic Species Restoration Facility (Mumma NASRF), Alamosa, CO. We met managers and/or staff at each facility and discussed current and past practices. Our objective was to identify and elaborate specific protocols applied to bonytail that were found to “work,” in contrast to others that have been tried and found to be unsuccessful or otherwise problematic. One other facility, Trinidad State Junior College (Trinidad SJC), Alamosa, CO, also raises bonytail as an extension of Mumma NASRF, but we did not visit this facility because the staff of Mumma NASFR provided the requested information.

Analysis and Tabulation of Annotations and Site Visits

We reviewed each available document (or LitID) for quantitative data and anecdotal (narrative) accounts of successful and unsuccessful experiences in bonytail culture as well as general information. If a document was found useful within the scope of this report, it is noted as such in the Bibliography table. These "useful" documents then were assembled in a second table titled "Biblio URID," into which we entered the LitID and assigned each a "unique record identification" number (URID). Each URID entry was associated with general data such as species (i.e., bonytail or humpback chub), age (e.g., juvenile), fish type (e.g., hatchery-produced broodstock manually spawned), and location names for any field, production or stocking data. In those cases when a LitID contained a variety of data (e.g., LitID 16, Tyus 1988, reported several capture locations), we assigned as many URIDs as necessary to the LitID and entered the aforementioned data where applicable. As for the LitID's unique data, we entered the URID and its data into one or more of a third group of tables titled "Diet_Feeding_Growth_Survival," Disease_Parasite _Medical," "Field_Capture," "Preference_Avoidance_Toxicity," "Rearing_Harvest_Stocking," "Spawning," and "Transport." Appendices 2-4 present these tables as well as their supporting tables and field names with brief descriptions. Site visit (personnel interview) data were maintained separately by facility name (Appendix 5).

Because of the broad range of available data, we made several data management decisions. We differentiated life stage by total length (TL) in mm because common naming practices were different at the various facilities and research units, (e.g., swim-up fry vs. sac-fry). We defined adults as fish greater than 150 mm TL, juveniles as 26-150 mm TL, and larvae as 25 mm TL or less. For sources that reported TL range instead of means, data were reported as either "larvae" or "juvenile" depending on the lower limit of the range (e.g., fish with TL range of 89-203 mm were reported as "juveniles"). In some cases, a combination "juvenile and adults" was reported and we maintained this as a distinct age category, but generally reported this information as "juvenile." For instances in which data were reported in English Units (including inches, pounds, gallons, acres or Fahrenheit, etc.) generally these were converted to the International System of Units (SI) (i.e., millimeters, grams, liters, hectares and Celsius, etc. respectively).

For fish length, some data were in fork (FL) and/or standard (SL) length. When possible, we used data from Snyder (1981) to convert FL to TL by applying a factor of 1.135 (e.g., 22 mm FL x 1.135 mm = 25 mm TL; as data in LitID 536); we did not determine a conversion factor SL measurements, and present data as is when applicable (as data in LitID 423).

We also chose to report growth as TL or weight change per unit time, and presented it as mm TL/month or g/month, respectively. We used 30 d as a standard month and 365 d as a standard year in all calculations.

We estimated days post hatch (DPH), and calculated and estimated growth from data and figures. Age 0+ are defined as fish 0-365 DPH (generally young-of-year up to the end of their first calendar year), Age 1+ fish are > 365-730 DPH, Age 2+ fish are > 730-1,095 DPH, Age 3+ fish are > 1,095-1,460 DPH and Age 4+ fish are > 1,460 DPH.

When we were able to identify individual bonytail year classes produced at Dexter NFH & TC, we assigned fish that were 0 DPH a nominal length of 6.8 mm TL and weight of 0.0028 g as starting points for growth calculations (Hamman 1982; LitID 889). We used this information for each growth rate iteration regardless of the number of DPH for any cohort. We assumed standardization would provide a representative overall growth rate over time. However, much of our data were from situations in which target-sized fish were culled out, and in these cases, our estimates of growth may not have been accurate representations of actual growth. Likewise, when facilities removed only large fish they also reduced pond density at the same time. A density dependent growth surge is a possible result, which may not be reflected in the next set of growth calculations because of the standard starting point we used. When data were from a controlled experiment and DPH were not provided, we used experimental days to calculate growth between data points (e.g., if fish were measured every 10 d for 30 days, then we calculated growth was for 10 d increments). Finally, fish within any given year class could have originated from either manual spawning or “volunteer” pond production. We attempted to identify these within literature sources to evaluate growth separately for each type of propagation. We do not report growth for multiple year classes that were stocked into the same site unless individual year classes could be accurately identified (e.g., by permanent tags).

At each of the production/rearing sites visited, we first toured the facility and then interviewed management and staff about bonytail development, harvest and stocking, growth, water chemistry, diet, disease, toxicity, predation, behavior, transport and handling for each life stage on station. It was during our visits that we determined that overall year class survival would be difficult to determine because many times fish kills were not reported and accurate mortality numbers were not available. As a professional courtesy, we present rearing mishaps or errors as generalizations instead of by named facility.

Once all of the data were entered into Access, the database was transferred into Microsoft ® SQL Server 2005 so that data queries could be written with more standardized SQL language. Our queries were by life stage in an effort to determine effects of diet, feeding, facility, handling, health, holding method toxicity and water chemistry on growth for each group. Site visit data were not queried and are instead presented in tables when applicable. Our research and management recommendations were generated from review of the queries and site visit data.

RESULTS AND DISCUSSION

Annotated Bibliographies

We selected 1,468 potential sources of bonytail rearing information from the 2005 update of the "Bibliographies for Native Colorado Big River Fishes," (Marsh et al., 2005). We added an additional 450 sources from searches of academic and institutional libraries, internet-based searches, communications with state and federal agencies, and other personal contacts for 1,918 potential sources of information. We manually reviewed each of these citations by title and identified 501 sources for critical review. Of these, 293 were deemed useful within the scope of this report, including 31 that dealt with bonytail genetics and nine that could not be located for review (Appendix 1); 168 were found not useful upon review. All 499 available sources were acquired and physically copied, and accompany this report.

Of the 293 useful citations (not including the genetics reports), 123 were included by Marsh et al. (2005), 72 were from two Endnote ® The Thomson Corporation libraries housed at Arizona State University, and 98 were from other sources. These citations all are presented in Appendix 6-8, alphabetically by author and year, numerically by year and alphabetically by author, and numerically by LitID number, respectively. LitID is included in the all appendices for ease of cross-referencing and physically locating hard copies of documents. Also included is a bibliography of sources in alphabetical order by author that were acquired, but were not useful for this literature review (Appendix 9).

Analysis and Tabulation of Annotations and Site Visits

Our comprehensive literature review demonstrated that most of our identified sources were not related to bonytail rearing practices. Often, rearing information was generally incomplete or information was omitted entirely. We attempted to fill information gaps by contacting report authors, and many times, we were successful.

Most of our empirical data came from annual facility reports, but these also lacked the detailed information we were most interested in reviewing. We asked every facility except Uvalde NFH for anything similar to production reports; however, few reports were written, although generally annual fiscal year reports were available from Wahweap SFH and Mumma NASRF. Data from Willow Beach NFH was limited to only two annual reports, which had few data, and apparently, in general, few records were maintained regarding bonytail rearing practices prior to the last four years (Willow Beach NFH, FWS, pers. comm.). When possible we included growth rates for these locations. Complete texts from site visits are presented in Appendix 10. In addition, at the time of the site visits we only had a basic knowledge of bonytail culture. As the literature review progressed, we had follow-up questions and data requests that could not be addressed in time for inclusion in this report. These are summarized and accompanied by other requested information in Appendix 11.

As a preface to the analysis that follows, we submit to the reader that many factors are known to affect fish growth such as fish density and water temperature, and that our process of independently reviewing these factors may result in subjective assessments. However, it was our intention to identify key characteristics of each production environment, either positive or negative, that may contribute to more or less efficient growth with more or less variation within a single year class as bonytail attain the desired stocking sizes.

The following life stage analyses were based only on literature sources that contained length and/or weight data for growth calculations. For site visit data, we attempted to separate information by life stage; this was generally not possible with adult and juvenile data.

Adult bonytail diet and feeding practices

Only eleven citations reported diet and feeding practice information accompanied by adult length and/or weight data. This may be because few studies, stockings, etc. have been with adult fish > 150 mm TL, our cutoff size for classifying adult bonytail. Future research and stockings likely will provide more information -- the target release sizes are 200+ mm TL for upper Colorado River basin fish and 250+ mm TL for lower Colorado River basin fish. “Commercial diet and natural pond productivity,” “commercial diet” (without any supplementation) and “naturally available organisms” were the three diet items associated with adult bonytail, but none of the documents detailed the actual pond organisms or listed their diets’ brand names and their manufacturers (Table 1). A review of historical facility records may be needed to determine actual feed brands and manufacturers at the time. See Appendix 12 for a summary of diet items associated with wild and cultured bonytail and humpback chub.

Approximately 10 mm TL/month was the greatest adult growth rate presented in the data, with fish feeding on a combination of commercial diet and natural pond productivity. However, these were the youngest bonytail adults in the dataset (Age 1+ versus ages 2-14+) and their growth reflects the typical rapid first year’s growth, which was not included in the data for the other fish. In contrast, the lowest adult growth rate of 0.29 mm TL/month was for bonytail in an experimental situation in which they were fed commercial diet only without any supplementation. The wild adult humpback in Westwater Canyon, UT had better growth than the experimental fish with 1.3 mm TL/month on naturally available organisms.

As for the facilities we visited, they each use different diets and feeding practices so we did not attempt to determine which diets and feeding practices exactly affected growth. Instead we present generalizations about growth based on what is practiced. All six facilities fed their adult bonytail a commercial razorback sucker diet, variously known as grower, 0301 or Bozeman, developed at U.S. Fish & Wildlife Service Bozeman Fish

Technology Center (Bozeman, MT) and manufactured only by Nelson & Sons, Inc. (Murray, UT). Some facilities supplemented or alternatively used salmon and trout diets (also manufactured by Nelson & Sons, Inc.) (Table 2). Wahweap SFH used the razorback diet for their bonytail for the first time this year (2006) while the other facilities have used it for several years; Uvalde NFH has only had bonytail on station since April 2006 and only feeds razorback diet. We were unable to determine the timeline of events leading to the use of razorback diet to bonytail at these facilities. Achii Hanyo Native FH fed whatever diets were available from their feed source, Willow Beach NFH, and these generally included razorback and trout feed. This was not necessarily helpful for growth because fish go off feed for approximately five days every time a feed change occurred.

Only one source reported diet size with their bonytail receiving a pellet diet although the actual size of the pellet was not reported (Table 1). Site-visit facilities fed a variety of diet sizes depending on fish size, but adults only received pellets, listed here in manufactures' production sizes: 3/32 inch (2.38 mm), 2.5 mm, 3 mm, 4.0 mm, 3/16 inch (4.8 mm), 6.0 mm pellet and 1/4 inch (6.4 mm) (Table 2A). Willow Beach NFH did not recommend feeding any pellet over 4.00 mm to adult fish on their station, while Dexter NFH & TC fed their older, larger brood fish the large pellet sizes [6.0 mm pellet and 1/4 inch (6.4 mm)].

Along with diet size is diet type; however, none of the sources reported the type of diet, i.e., whether the feed was sinking, slow sinking or floating (Table 1). Site-visit facilities all reported using all three diet types; however, some facility managers mentioned preferring slow sinking feed over sinking feeds (Table 2A), but it is unknown if they meant this type of feed for only adult bonytail.

Only one source reported feed quantity with their bonytail receiving 4-5% of their body weight (BW)/d, but it did not appear to help length growth, which was 0.29 mm TL/month (Table 1). There was no mention in this report if they adjusted the amount of feed as fish mortality increased and fish number and density decreased. For all facilities, feed quantity ranged from 1-5% BW/d (Table 3); it is unknown if there were adjustments for fish density changes from natural mortality, predation, or harvest. At Willow Beach NFH, smaller fish generally were fed at 4% BW/d when first stocked into the system in late winter/early spring, but as water temperatures increased during summer, the quantity fed was decreased to 1% BW/d because particulate matter would increase substantially at a higher feed rate and overload the outdoor recirculating system. Other general feeding comments are summarized in Table 3A.

From the literature review, we were unable to determine differences in growth in similar holding types between fish with supplemental versus no supplemental food sources (Table 1). From our facilities visits, Wahweap SFH and Mumma NASRF reared their fish in lined ponds, whereas Willow Beach NFH used concrete raceways and Achii Hanyo Native FH used earthen ponds. Dexter NFH & TC is the only facility that produced fish both intensively (indoor tanks and outdoor raceways) and extensively (ponds only), and they reported that fish raised extensively were more robust than those raised intensively. Uvalde NFH also used both lined and earthen ponds (extensively) as well as raceways (intensively). When we compared the data for these two holding types at Dexter NFH & TC, we were unable to determine if growth was consistently better for one versus the other because of differences in fish density and other unknowns such as the number and size of holding tanks (Table 4).

We were unable to determine if feeding time affected growth because none of the sources reported feeding time. Facility interviewees reported feeding times that ranged from “first thing in the morning” and sunrise to early afternoon and evening (Table 3). Only one source reported feeding frequency with their bonytail fed daily, but it did not appear to help growth, which was 0.29 mm TL/month (Table 1). Our facilities’ feeding frequency ranged from one time/d to four times/d, and from five days/week to seven days/week (Table 3). All of the facilities overwintered small fish that did not reach harvest size and most continued feeding fish even if it was only once a week.

Wahweap SFH stopped all major feeding from October to March (Table 5). We were unable to determine if growth was affected by feeding method, i.e., fish fed by hand or with an automatic feeder because none of the sources reported this practice (Table 1). Among facilities, Achii Hanyo Native FH and Uvalde NFH used both, Willow Beach NFH used belt feeders, and Mumma NASRF, Dexter NFH & TC and Wahweap SFH all fed by hand (Table 3).

By using either DPH or years post hatch (YPH) as our estimator of holding time, adult growth in length remained steady at 5-7 mm TL/month over many years, but then eventually decreased to less than 4 mm TL/month as reported for 10-14 year old fish (Table 1). Dexter NFH & TC reported to us that once fish attained 300 mm TL (12 inches) in the second year on station that it was generally difficult to continue to get faster length growth thereafter. Similarly, Willow Beach NFH reported to us that at their facility once bonytail reached 330-375 mm TL (13-15 inches), length growth slowed down and the fish generally only gained weight growth thereafter.

We were unable to determine any growth differences in fish fed medicated versus non-medicated feed because none of the sources reported using medicated feed. Achii Hanyo Native FH, Uvalde NFH and Willow Beach NFH were the only facilities who used medicated feed and they did not report any issues with fish growth.

Handling adult bonytail

Only eight citations with adult length and/or weight data also contained handling information. Of the handling categories we identified during the literature review (tag, measure, weigh, photograph, scale sample, and tissue sample), only one literature source reported both PIT (passive integrated transponder) tags and tissue sampling, and none of the sources reported photographs taken or scales sampled (Table 6). The single citation also reported an outbreak of white-spot or "*Ich*." What was not reported was if the *Ich* was observed at the tagging or tissue sampling sites as they used an invasive surgical procedure to remove tissue, which may have affected not only growth but survival; only 28% of fish in the study survived.

Hatchery-produced bonytail typically are tagged (wire, coded wire or PIT tags) generally only when they are about to leave the station for field stocking. Generally, only wild fish are photographed and sampled (scale and tissue), although Dexter NFH & TC recently completed tissue sampling of their brood fish for genetic analysis and we do not know the effect this may have had on their growth. In general, Willow Beach NFH and Achii Hanyo Native FH do not handle fish (measure and weigh) once they are on station. If fish must be handled at these two facilities, such handling is only from November or December to approximately March when water temperatures are cooler (Table 7); all facilities suffer extreme high water temperatures (e.g., up to 32 ^{o}C at Trinidad SJC) during the summer months and a only few reported shading fish with either permanent or floating structures (Table 7A). Wahweap SFH, Uvalde NFH and Dexter NFH & TC handle their fish (weigh and measure) at least annually when they are moved to fresh ponds or when culling ponds for larger fish, although Wahweap generally limits their handling in August. Dexter NFH & TC usually only handles its fish in the autumn before Thanksgiving, with the exception of broodstock for manual spawning in late April or early May. Uvalde NFH samples fish monthly except during July, August and September, using a cast net.

At Mumma NASRF, Dexter NFH & TC and Willow Beach NFH, feed is withheld one day prior to tagging, while at Wahweap SFH, fish may be off feed from three days to as long as six weeks by the time they are PIT-tagged (Table 7). Also at Wahweap SFH, fish are generally tagged and returned to fresh ponds for holding from five days to five weeks post-tagging; they are not transported the same day as tagging. This allowed for mortality observation and it was found that less than 10 fish/week died; Mumma NASRF also reported only losing 10 fish to tagging efforts. This is similar to Uvalde NFH who hold fish seven to ten days after handling. At all of the other facilities, fish are generally held for only a few days post tagging then stocked out into the field.

Harvest is a potential pre-stressor to tagging that could also affect growth. Wahweap SFH drained ponds in three to four hours, which was similar to Mumma NASRF rapid drain time of two to four hours, but both drained ponds overnight if fish appeared stressed as did Dexter NFH & TC (Table 8). Conversely, Achii Hanyo spent several weeks slowly draining their ponds with a final rapid drain the night before harvest. All facilities then crowd the fish toward the ponds' kettles and then dip out the fish with nets into tubs or tanks; Uvalde NFH uses an auto crane to take fish out. Willow Beach NFH crowded their fish at the end of the raceways. It should also be noted here that Willow Beach NFH lowered the water temperature one day to one week prior to harvest. Wahweap SFH may drain and refill ponds up to four times during tagging, but by the fourth time, all of the fish were removed due to deteriorated water quality.

After the stress of harvest, fish were generally measured and weighed. Over time TL and weight growth in adults leveled off then it decreased, but whether this was due to physical handing from measuring and weighing fish was unknown (Table 1). Most adults are stocked out of facilities once they reach target size and they are not transferred to other facilities to monitor this variable, and many times only a portion of fish were measured, leaving a majority of fish unhandled. One source reviewed found that with a mixture of juveniles and adults (101-173 mm TL), bonytail that were repeatedly recaptured then measured and weighed grew less in length and weight than those not recaptured; these fish were also PIT-tagged, but tagging did not necessarily affect growth (Paukert et al. 2005; LitID 1858).

Water chemistry and adult bonytail

Ten citations contained water chemistry data, but only one also reported length and/or weight data for adults (Table 9). Most facilities had at least sporadic water chemistry analysis (Table 10 and 10A). Mumma NASRF had adequate quantities of warm well water available to keep their ponds at relatively stable water temperatures throughout the winter (approximately 21 ^{o}C) while most of the other facilities had to contend with ambient water temperatures. Willow Beach NFH also warmed the incoming water to their raceways, but it could only be warmed so much in the winter because their solar panels were not efficient enough.

Few water chemistry parameters were reported for adult bonytail in the literature (Table 9). In one experiment, the tanks were maintained at 13 ^{o}C, but this is not an optimal temperature for bonytail growth. Most facilities had high summer water temperatures, but no low dissolved oxygen issues were reported (Table 10). Adult bonytail survive well and grow in a variety of water chemistries at the various facilities including calcium (10-105 mg/L), magnesium (10-57 mg/L), sulphate (317-1901 mg/L), chloride (104-200 mg/L), total solids (820-4,564 mg/L), carbonate hardness as $CaCO_3$ (358-1,700 mg/L), alkalinity (127-269 mg/L), pH (7.5-9) and dissolved oxygen (<3-15 mg/L) (Table 10A).

Adult bonytail reported in the one literature source were reared in well water, which did not necessarily appear to inhibit or promote growth; no other parameters besides temperature were reported (Table 9). Similarly five of seven of our facilities (including Trinidad SJC) reared their bonytail in well water while Willow Beach NFH and Achii Hanyo Native FH reared bonytail in Colorado River water (Table 11). The only obvious thing we saw between the two water sources is the “aliveness” of river water versus well water. Importantly, both Willow Beach NFH and Achii Hanyo Native FH contend with disease outbreaks and treatment needs year round whereas others generally do not.

Holding adult bonytail and fish density

Eight sources reported holding method and fish density along with length and/or weight data for adult bonytail. With the exception a single report of an indoor tank, all of the holding methods were the same - outdoor ponds (Table 12). When fish density was calculated, ponds had the greatest density and the greatest growth, but this may have been a reflection of the age of the adults (Age 1+ and Age 2+ versus Age 2+ and Age 3+); the density range was 3,530 fish/ac (1,412 fish/ha) to 7,203 fish/ac (2,881 fish/ha) (Table 12). As for the facilities we visited, Wahweap SFH reported Age 1+ fish attaining TLs of 8-9 inches (203-229 mm) TL at a fish density of 3-4K fish/0.4 ac pond (7,500-10K fish/ac or 3,035-4,047 fish/ha) while Dexter NFH & TC reported Age 1+ fish attaining 12 inches (305 mm) TL in a fish density of 10,000 fish/ac (4,000 fish/ha) (Table 13). Similarly, both facilities reported rearing Age 2+ at fish densities of 7,500-10K fish/ac (3,035-4,047 fish/ha) and 5,000 fish/ac (2,023 fish/ha), but TLs were not reported (Table 13). Dexter NFH & TC also reported fish density for Age 3+ fish at 2,500 fish/ac (1,012 fish/ha), but again TLs were not reported (Table 13). Both of these facilities rear their fish in lined ponds, but Wahweap SFH is a static system while Dexter NFH & TC is a flow-through system with 5-25 gal/min (19-95 L/min), which may or may not be a factor in density and growth (Table 13).

Health and disease in adult bonytail

Only one source reported a health issue along with data for growth, and that was for bonytail that were severely afflicted with *Ich* and those that survived only grew 0.29 mm TL/month; no treatment was reported. As for our facilities, only Wahweap SFH is annually certified disease free and if need be, their fish can travel the nation without any quarantine or treatment time (Table 14). Mumma NASRF, Trinidad SJC and Dexter NFH & TC are similar with generally no diseases on station requiring any treatment, although Trinidad SJC did have several severe *Ich* outbreaks in the past, Uvalde NFH had a mild bacterial episode one time in 2007 and Dexter NFH & TC occasionally treated incoming wild fish (Table 14). Willow Beach NFH and Achii Hanyo Native FH must regularly treat fish as long as fish are on station; they only decrease the frequency of treatments in the cooler months generally (Table 14). Both facilities treat disease outbreaks as they occur, which generally is in the summertime months.

Facility, spawning method and adult bonytail growth

The few citations with growth information suggested that Wahweap SFH had the greatest length growth of approximately 10 mm TL/month (1997 year class, 455 DPH, fish from manual spawn) over the greatest length growth from Dexter NFH & TC of 6.2 mm TL/month (1981 year class, 2,555 DPH, fish from manual spawn) (Table 1). When we reviewed facility growth for all facilities with length and/or weight data for adult fish, we found that for Age 2+ fish, Wahweap SFH had the greatest length growth of this age of fish, 13 mm TL/month (1996 year class, 765 DPH, fish from manual spawn) and Dexter NFH & TC had greatest weight growth at 4.1 g/month (1999 year class, 1,095 DPH, fish from natural pond production) (Table 15). For Age 3+ fish, Dexter NFH & TC had the greatest length growth of this age of fish, 6.1 mm TL/month (2001 year class, 1,460 DPH, fish from manual spawn) and Dexter NFH & TC had greatest weight growth at 4.1 g/month (1999 year class, 1,095 DPH, fish from natural pond production) (Table 16). For Age 4+ fish, Dexter NFH & TC had the greatest length growth of 6.2 mm TL/month and weight growth of 8.2 g (1981 year class, 2,555 DPH, fish from manual spawn) (Table 17).

Larvae and juvenile bonytail diet and feeding practices

We combined larval and juvenile diet and feeding practices because of how the data were generally reported. When possible we differentiated between the two life stages, clearly noting “larvae” when possible. However, for general reporting purposes from this point forward we combine larval and juvenile data and refer to these combined data as only “juvenile.”

Twenty-seven citations reported diet and feeding practice information as well as juvenile length and/or weight data. A variety of commercial diets were fed to juvenile fish, along with brine shrimp nauplii and natural pond organisms for larvae (Appendix 13). Some citations only listed “commercial diet,” while others listed brand name and manufacturer, and again the greatest length growth was with a generic “commercial diet and brine shrimp nauplii” combination with a length growth of 38 mm TL/month (Table 18). In fact, three of the four greatest growth rates calculated were for “commercial diets,” but the brands and manufacturer were not reported. Of the diets reported, the greatest length growth was from a combination of feeds by Nelson & Sons, Inc. (Murray, UT), Bozeman razorback and Silver Cup trout commercial diets, which produced an on-station length growth of 17 mm TL/month for bonytail at Dexter NFH & TC. The same length growth was found in an experimental situation using a combination of Biodiet Starter and Grower by Bio-Oregon, Inc. (Warrenton, OR) (Table 18). The growth observed at Dexter NFH & TC was during intensive rearing practices of larvae to juvenile for approximately 120 DPH, while the latter was for a 30-d experiment starting with 30 DPH fish that were exposed to a combination of water elements during a toxicity study. Most notable was a recent diet study comparing the effects of catfish, trout, and high- and low-protein shrimp diets on weight growth for juvenile bonytail (from Age 0+ fish starting at 275 DPH and ending at 395 DPH), with the high-protein shrimp diet affecting weight growth the most.

Natural pond organisms in Lake Mohave lakeside backwaters and naturally available organisms in the middle Green River wetlands created the greatest off-station length growth in bonytail overall, 30 and 25 mm TL/month, respectively, with the latter under mild experimental field conditions. Naturally available organisms did not appear to effect weight growth as significantly as they did length growth. Commercial diets of unknown brand and manufacturer presented the greatest growth in weight (Table 19). Of the known commercial diets, Nelson & Sons, Inc. (Murray, UT) Bozeman razorback commercial diet along with natural pond production produced an on-station weight growth of 7.9 g/month at Trinidad SJC for fish from Age 1 to Age 2. Most of the other commercial feeds produced weight growth from 0.64-2.8 g/month in both production and experimental settings (Table 19).

Burdick and Hamman (1993; LitID 1639) reported exceptional bonytail fork length growth of 24-26 mm/month during their second year on station; commercial salmon diet supplemented with natural pond organisms was used as feed. Fish density was very low at the start of the experiment (30 fish/0.1 ac or 300 fish/ac or 121 fish/ha) and decreased significantly as mortality significantly increased (Appendix 13). This reported growth rate was derived from only 15 surviving fish at 343 d. It was not reported whether efforts were made to maintain natural pond productivity during the third year of the experiment and it is unknown if this was a factor in the decreased growth.

Commercial razorback diet was commonly associated with the greatest length growths reported in the literature. This diet is also preferred and used most at the facilities we visited (Table 2). Dexter NFH & TC, Willow Beach NFH and Achii Hanyo Native FH all use a combination of razorback and trout diets although ratios or usage times were not reported. A variety of diet sizes were reported in the literature including Starter diet, Number 1, 2, 3 and 4 crumbles, and 2.4 mm and 1/8 inch (3.18 mm) pellets (Appendix 13) that were also fed at facilities we visited (Table 2). None of the literature reported diet type (i.e., floating, sinking or slow sinking) (Appendix 13). All five site-visit facilities reported using all three diet types; however, some facility managers mentioned preferring slow sinking feed over sinking feeds (Table 2).

As for larvae, Willow Beach NFH started their larvae on brine shrimp nauplii which was fed ad libitum for 14-21 d followed by a powdered diet (Appendix 14) then commercial diets (Table 20 and Table 20A). In the past, they have fed California Black Worms (Worm Man’s Worm Farm, Monroe Township, NJ) and frozen brine shrimp. Mumma NASRF, Wahweap SFH and Dexter NFH & TC also all start their larvae on brine shrimp nauplii; however, larvae at Wahweap SFH were only fed brine shrimp for two days before their release into open ponds from holding cages maintained within ponds; fish later were fed commercial diets; larvae at Uvalde NFH fed on natural pond production only until commercial diet was started (Table 20). Mumma NASRF larvae were held indoors until they were 13-19 mm (0.5-0.75 in) and fed appropriately sized razorback diet. Dexter NFH & TC may also hold their larvae indoors and rear them intensively such that they do not receive any natural production, and only are fed brine shrimp nauplii and razorback and trout diets (Table 20A).

Only six sources reported feed quantity, although they reported several types, from 0.25 ml or 0.5 ml suspension of brine shrimp, 0.25-0.50 kg feed/system/d, ad libitum, ad libitum at 10% avg BW/d, 0.5 to 3% BW/d and “a pinch of feed” (Appendix 13). Only one of these (ad libitum at 10% avg BW/d) also reported bonytail growth, although it was the toxicology study previously mentioned for high fork length growth. For all facilities, feed quantity ranged from 1-5% BW/d, which was adjusted at Willow Beach NFH due to water quality issues and not necessarily to accommodate changes in fish density (Table 3). Uvalde NFH reported 2-3% BW/d, Dexter NFH & TC and Mumma NASRF both report feeding at 3% BW/d whereas Wahweap SFH reports 5% BW/d or lower as determined by sampling.

National Wildlife Refuge ponds and lakeside backwaters that are earthen and unlined versus outdoor, lined ponds appear to have slightly greater length and weight growth than lined ponds at hatchery facilities (Table 21). This may be related to the quality (species composition) and quantity of natural plankton production in the two pond types. It was not reported if golf course ponds were earthen or lined, but most such ponds have at least a bentonite layer.

Lake Mohave backwaters and Dexter NFH & TC both had some of the greatest length growth among holding types, although only Dexter NFH & TC had some of the greatest weight growth. As reported previously, Wahweap SFH, Mumma NASRF and Dexter NFH & TC all reared their fish in lined ponds, whereas Willow Beach NFH used concrete raceways and Achii Hanyo Native FH used earthen ponds; Uvalde NFH used both earthen and lined ponds. All six facilities had various amounts and types of natural production. Wahweap SFH reported 14 organisms/L in an average pond water sample.

As for feeding practices, only one citation reported a “dusk” feeding time (at Dexter NFH & TC) associated with sizeable length and weight growth, and two sources reported feeding frequency with their bonytail fed daily and at 4-5 times/d (Appendix 13). We were unable to determine if growth was affected by the method feeding, i.e., fish fed by hand or with an automatic feeder, because only one of the citations reported method of feeding (hand feed).

Similar to the adult data and using DPH as our estimator of holding time, it appeared that the longer fish were on station the more growth tended to slow down over the course of time (Appendix 15). When we looked at length and weight growth by DPH for Age 0 fish from the literature, we found that the greatest growth occurred during the first 150 DPH, then decreased by approximately 50 percent as fish aged to 365 DPH (Table 22). No similar distinctions could be made with Age 1+ fish other than growth appeared to remain steady from 365 to 730 DPH (Table 23 and Appendix 16).

Also similar to the adults, we were unable to determine any growth differences in fish fed medicated versus non-medicated feed as none of the citations reported using medicated feed.

Handling juvenile bonytail

Twenty-three citations contained juvenile length and/or weight data associated with handling information (Appendix 17). Of the handling categories we identified in the literature review (tag, measure, weigh, photograph, scale sample, and tissue sample), only one literature source reported PIT (passive integrated transponder) tags for bonytail, but overall survival was low and growth was reported in fork length (Burdick and Hamman 1993; LitID 1639). None of the literature reported photograph, scales or tissue samples taken. As reported above, growth may be affected by PIT tagging fish, which could be observed on station if facilities were holding fish, but no information was found in the literature review. Further, harvest is a potential pre-stressor to tagging and could also affect growth; however, no significant effects could be seen in juveniles as DPH increased (Appendix 17).

Water chemistry and juvenile bonytail

Seven citations reported water chemistry and length and/or weight data for juveniles, from both production facilities and experimental studies (Appendix 18), while most of the facilities we visited had sporadic water chemistry analysis (Table 9). Only four citations presented growth data with water chemistry parameters (Table 24). Where reported, fish were reared in spring, filtered, reconstituted and Colorado River water, in flow-through and recirculating systems. None of the parameters appeared to affect growth. Juvenile bonytail survived and grew in waters with dissolved oxygen ranging from 6.4-10.6 mg/L, pH from 7.8-9, as well as several other parameters as presented in Table 24. These all are well within known tolerance limits for fishes. Appendices 19 and 20 present growth and survival of bonytail and humpback chub eggs (fertilized ova), larvae, and juveniles in water chemistry experiments and toxicological experiments. Site visit facilities' water chemistry is reported above in "Water chemistry and adult bonytail."

Holding method and practice and juvenile bonytail density

Twenty-four citations reported holding method with length and/or weight data for juveniles. Holding method was either fish held indoors or outdoors, and was not associated with differences in growth (Appendix 21). Most fish were outdoors by the end of Age 0 except for some fish that were used in controlled laboratory experiments. We compared fish at 150 DPH for growth with indoor and outdoor holding as well as type of holding method, and we could not determine any significant differences (Table

25). Only two citations reported pond size for fish density calculations, and only one source reported the same size pond with different fish densities. We found no difference in growth for approximately 36K fish/ac (15 fish/ha) versus 25K fish/ac (10K fish/ha) (Table 26 and Appendix 21). Appendix 22 reports holding and fish density information for larval bonytail and humpback chub.

In 2005, Achii Hanyo Native FH reported stocking 125 mm TL mean bonytail received from Willow Beach NFH in mid-March. This stocking produced 250-300 mm TL mean bonytail in mid-December of the same year for an approximate length growth of 16-22 mm TL/m. Their pond stocking density was 5,000 fish/0.6 ac pond, 5,500 fish/0.8 ac pond, and 2,500 fish/0.4 ac pond (8,333 fish/ac or 3,333 fish/ha, 6,875 fish/ac or 2,750 fish/ha, and 6,250 fish/ac or 2,500 fish/ha, respectively). A fourth pond holds “shorts” and volunteer spawn. Approximately 6,000 fish total were harvested (30% survival in all ponds).

Dexter NFH & TC reported generally stocking 0.3-1 ac (0.12-0.40 ha) ponds with bonytail. Nominal stocking rates were 100,000 young-of-year (YOY) fish/ac (40,000 fish/ha) into 1 ac (0.40 ha) ponds, 10,000 Age 1 fish/ac (4,000 fish/ha) into 1 ac ponds, 5,000 Age 2 fish/acre (2,000 fish/ha) into 1 ac ponds, and adults ranged from 95 (317 fish/ac or 128 fish/ha) to 500 fish (2,000 fish/ac or 800 fish/ha) to 5,000 fish/ac (2,000 fish/ha). First year fish grow was approximately 25 mm TL. Dexter NFH & TC suggested if pond survival was less than 50% then something went wrong in the pond.

In 2005, Mumma NASRF reported stocking 17,000 YOY fish/0.1 ac pond (170,000 fish/ac or 68,000 fish/ha), while another pond held 5,000 Age 1 fish/0.1 ac pond (50,000 fish/ac or 20,000 fish/ha). Growth is generally 76-102 mm TL for YOY fish and Age 1 fish on station, which was 6-8 mm TL/m.

Willow Beach NFH reported they receive a variety of sizes and numbers of fish from Dexter NFH & TC annually. Annual (first year) growth of fish received as larvae or very young juveniles was 150-200 mm TL (12-16 mm TL/m). Fish averaged 250 mm TL (10 mm TL/m average) at the end two years on station. Depending on size at receipt, some slow growing fish took three to four years to reach 350 mm TL, which was a growth of 7-9 mm TL/m.

Wahweap SFH reported that they receive larvae from Dexter NFH & TC and generally stock 10-20,000 YOY fish/0.4 ac pond (25,000-50,000 fish/ac or 10,000-20,000 fish/ha), 3-4,000 Age 1 fish/0.4 pond (7,500 fish/ac or 3,000 fish/ha). At the end of their first year on station, YOY fish averaged 120 mm TL (10 mm TL/m) and fish averaged 225 mm TL by autumn of their second year on station (approximately 515 DPH) for a length growth of 13 mm TL/m.

Bonytail larvae and fingerlings were first stocked at Uvalde NFH in May 2006 for use in at least two research studies, 1) handling and transport, and 2) density and growth. Growth and survival in the first study was excellent with 80% of 3,000 15 cm bonytail originally stocked into ponds attaining target size of 300+ mm TL within six months of stocking, with an average survival for all ponds of 92% (FWS 2006; LITID 1975 and G. Webber, Uvalde NFH, pers. comm.). In the second study, four to six inch fish (from larvae reared at Uvalde NFH) were stocked into six ponds in April 2007, with three ponds receiving 1,000 fish/pond and three other ponds with 1,500 fish/pond; excess fish were kept in raceways on station. These ponds will be harvested in October 2007 and growth and survival will be determined.

Health and disease in juvenile bonytail

Only one source reported a health issue and data for juvenile growth, and bonytail in this instance suffered and succumbed to *Ich* during an experiment (Burdick and Hamman 1993, LitID 1639). Appendix 23 reports general treatments for non-specified diseases and other health issues for all life stages, while Appendices 24 and 25 report specific diseases, health issues and treatments. Site visit facility health and treatment is provided in the adult comments above.

Facility, spawning method, and juvenile bonytail growth

From relatively few citations, Dexter NFH & TC and Wahweap SFH had similar growth of Age 0+ juveniles at 150 DPH. Bonytail growth decreased and stabilized after one year on station (Table 21). Similarly for Age 1+ fish, the literature reported that facilities had stable growth. Dexter NFH & TC had the highest length growth at the end of second year on station (Table 22). Bonytail from manually spawned fish had generally lower length growth than bonytail produced by volunteer spawning in holding ponds (Table 27). At 150 DPH, 2000 and 2003 year classes produced by manual spawning and reared at Wahweap SFH had generally smaller length growth than fish of the same year class produced naturally at Dexter NFH & TC. At 365 DPH, the opposite was true for the 2002-year class as manually spawned fish at Wahweap SFH were slightly larger than both manually spawned and naturally spawned fish at Dexter NFH & TC. This was not true for the 2000-year class of which the naturally produced bonytail at Dexter NFH & TC were almost twice the length of those at Wahweap SFH. Fish from the 2003-year class at Mumma NASRF and Wahweap SFH had approximately the same length growth at 730 DPH, whereas 1999 year class of manually spawned fish at Wahweap SFH fish were smaller that those naturally produced at Dexter NFH & TC at 730 DPH.

RESEARCH AND MANAGEMENT RECOMMENDATIONS

In our literature review, a combination of commercial razorback and trout diets (augmented with natural pond production) produced the best growth rate for bonytail and a commercial salmon diet was associated with the highest growth rate for humpback chub. All of the facilities we visited used either razorback or trout diets for juvenile bonytail (most augmented with natural pond productivity). Some users expressed an overall preference for the razorback diet over the trout diet. Henne et al. 2006 (LitID 811) tested four diets on early juvenile stage bonytail and found that a commercial, high protein shrimp diet produced the highest growth rate in bonytail versus low protein shrimp, catfish and trout diets. We suggest follow-up studies to the Henne et al. (2006) study with larger bonytail that includes feeding time as discussed below. We also suggest performing much of the dietary investigation under both pond and laboratory conditions with and without supplemental natural pond production, respectively, and we suggest treatments to include combinations of commercial feeds.

We also recommend developing a specific diet for bonytail, as has been done for razorback sucker, based in part on the diet items found in wild bonytail and humpback chub listed in Appendix 13. We suggest several avenues of investigation, including experimentation with attractants (see Stickney 1993) for increased palatability and feed intake. Growth effects of style of feed also should be examined, such as a slow sinking variety as preferred by some facility managers and staff. Mueller et al. 2005 (LitID 277) suggested that as fish grew larger, their preferred diet items may change, similarly to what is presented in Appendix 13. Few of the facilities we visited reported what species of natural pond productivity were present and at what densities. Further, at Achii Hanyo NFH there apparently are non-native fish eggs and larvae that pass through the filter system and end up in the rearing ponds, and these represent a potential but unquantified bonytail food resource. We suggest that initial assessments occur to determine what is exactly available for fish at the varying life stages. It may be that the razorback, trout and/or salmon diets are suitable for smaller bonytail, but a specialized diet may be necessary for juvenile fish greater than a certain size. The razorback diet, for example, is reported to have three times more vitamins than standard fish diets (C. Nelson, Nelson & Sons, Inc., pers. comm.). However, it is unknown if this formulation would be too rich (or too lean) for bonytail.

Bonytail feed from dusk to dawn, yet many facilities only fed during the day and in some cases only once a day. From other fish species research, rainbow trout fed at times other than dawn had significantly reduced growth (Boujard et al. 1995 and Bolliet et al. 2000) whereas several species of catfish had improved growth when fed at night (Bolliet et al. 2001). It is also possible that bonytail of various sizes feed at different times of the day due to competition and/or predation. Bonytail feeding times may be seasonally affected by photoperiod, as reported for rainbow trout (Bolliet et al. 2001), or by water temperature as reported at several of the facilities we visited. Feeding time may also have an effect on endocrine products (Noeske-Hallin et al. 1985 and Bolliet et al. 2001) which in turn may have an effect on growth via sexual dimorphism (discussed below). In the only published bonytail diet study, fish were fed four times/d during photoperiods observed during early February through early June, and in this case both frequency and photoperiod could have affected growth in addition to diet (Henne et al. 2006; LitID 811).

We suggest determining the effect on growth of one feeding per day in the daytime or evening versus several meals per day throughout the day and/or night. Depending on results of these studies, we might then recommend adding automatic feeders so that evening, dawn or dusk feedings could be used to augment any daytime feeding. We suggest this in particular for upper basin facilities whose growing season is a short, 4.5-5 months (Wydoski 1994; LitID 374). Similarly, water temperatures are cooler earlier and longer in the upper basin as reported by facilities that we visited. Escandon (1994; LitID 1165) reported that standard metabolic rates for bonytail were significantly lower at 15^{o}C (59 ^{o}F). This is only a few degrees higher than reported for 50 ^{o}F (10 ^{o}C) at which growth ceases in bonytail (Wydoski 1994; LitID 374). By adding more feedings at appropriate time(s) of day, bonytail may exhibit higher growth rates. Several facilities also mentioned using “bug lights” to attract insects that are a natural source of food for bonytail. We suggest this practice at all facilities if possible. We caution that feeding commercial feed at night without sufficient aeration may cause dissolved oxygen issues if uneaten food is allowed to accumulate (see Robinson et al. 1995).

Likewise, feeding rate may be an issue for bonytail. Piper et al. (1982) suggested that as fish grew on station, the amount of feed fed would actually decrease (i.e., decrease percent body weight fed/d). We suggest experimenting with percent body weight for the facilities that are on the low end (1% BW/d) as well as the facilities on the high end (5% BW/d). It may be that in the middle at 3% BW/d is more efficient. Dexter NFH & TC had the best growth rate for juveniles and Mumma NASRF had the best pond survival at this rate. We suggest that feeding rate experimentation coincide with the feeding time investigations recommended above. In addition, we noted that “ad libitum” feeding was a common practice for larval and early juvenile indoor culture. While we respect and concur that rearing fish is “an art,” we suggest that when possible, more effort be applied to determining amounts, densities and volumes of feed. Only in this way, can optimal rations be determined and maintained.

Variation in growth within year class is a common phenomenon among hatchery-reared bonytail, reported in both the literature review and during site-visits. Typically, three within-cohort size classes were identified: “fast,” “regular,” and “slow” growers (approximately 10, 80 and 10% of the group, respectively). This variation presented itself again when slow growers were restocked into new ponds and allowed to grow to target size, which meant another year or two on station in some cases. Dexter NFH & TC suggested that the largest fish at ages 0-2 in a year class were generally female and cautioned that the larger target size at stocking may result in mostly stocking female fish. It is possible that bonytail are a thermal-sensitive fish species, with similarities to sea bass whose juveniles when exposed to low temperatures (13 and 15 ^{o}C) matured into females while those exposed to a higher temperature (20 ^{o}C) more often developed into males (Pavlidis et al. 2000); maturation generally occurred some time before 64 DPH at 20 ^{o}C. We suggest for at least one year, field stocking month be adjusted to within a month of hatchery spawning time when bonytail begin to exhibit their external sexual characteristics so that sex can be more reliably determined now that adult-sized fish are the target stocking size basin-wide. We further recommend experiments under laboratory conditions to assess onset of sexual maturity as a function of temperature and age (DPH). We also suggest that a statistical sample of the slow growers be sacrificed to determine their gender. Similarly, several facilities annually sort their fish to move them to fresh ponds, reduce pond density, or cull out fish for harvest. If facility space allows, we suggest experimenting with at least biannual sorting which may further help reduce variation in growth with year class. This would remove the larger, more aggressive bonytails who bully smaller fish at feeding time(s) as reported by several of the hatcheries we visited and as suggested in a refugium setting (Mueller et al. 2005; LitID 277).

We suggest flow studies to determine if flow added to static and low flow ponds and raceways would increase energy expended, which in turn would increase feeding and perhaps add growth. Escandon (1994; LitID 1165) reported active metabolic rate in juvenile bonytail increased significantly with swimming speed, with the greatest rate at 20^{o}C, and we recommend research to determine if this in turn would stimulate more feeding which in turn would produce more growth. This flow conditioning could benefit bonytail for stocking as reported or suggested in several studies [Chart and Cranney 1993 (LitID 57), Wydoski 1994 (LitID 374), Badame and Hudson 2003 (LitID 1428), Ward 2003 (LitID 521) and Burke 2006 (LitID 1953)]. We caution that increased metabolism would increase oxygen consumption (Piper et al. 1982) and in several of the facilities we visited, this may be a problem, especially during the summer months when water temperatures are at their highest and no aeration is used.

Hanson et al. 2006 (LitID 1952) reported slight differences in final lengths of bonytail infected with Asian tapeworm (*Bothriocephalus acheilognathi*), and this parasite as well as anchor worm (*Lernaea cyprinacea*) are common among many of the facilities we visited. We suggest these facilities monitor bonytail growth closely, particularly once larger juveniles are on station such as at Willow Beach NFH and Achii Hanyo Native FH. Both of these facilities prophylacticly treat their fish the whole time they are on station as well as treat disease outbreaks when they occur, but it is unknown if these treatments affect growth. After monitoring growth of several year classes on station, it should be determinable if their disease treatments affected growth.

All stations reported volunteer spawn in ponds, and Wahweap SFH and Dexter NFH & TC reported that this type of spawn was common for fish as young as one to two years old. Mueller 2006 (LitID 1857) reported female bonytail as small as 100 mm were reproductive at Cibola High Levee Pond. Dexter NFH & TC annually distributes volunteer spawn either to Willow Beach NFH or directly to lower Colorado River waters, Achii Hanyo Native FH, Willow Beach NFH and Mumma NASRF hold over volunteer spawn, but at Wahweap SFH, fish produced this way are considered a nuisance. One suggestion from a hatchery facility was to find methods that would prevent bonytail from spawning and use their energy only for growth and not reproduction. Atlantic cod reared under constant light (24 h light) in laboratory conditions delayed their spawning, added weight, and reached target size before spawning (Karlsen et al. 2006). Karlsen et al. (2006) also reported works by others who suggested that limiting the amount of energy in the feed, particularly lipids, would also inhibit cod from developing gonads because they would not have the energy stores in their bodies available for reproduction. We recommend investigating these potential methods of reproductive control under controlled laboratory conditions and if successful, under hatchery conditions as well.

To date, Wahweap SFH has disposed of more than 100,000 bonytail from volunteer spawn as a direct result of the state of Utah fish policy, and apparently with the knowledge and concurrence of the Biology Committee for the Recovery Implementation Program for the endangered fishes of the upper Colorado River basin (Gustaveson and Bradwisch 2002; LitID 1905). We recommend that the state of Utah's surplus fish be stocked into off-channel habitats or elsewhere instead of being unnecessarily wasted. Suitable off-channel habitats can be identified or created, and “excess” fish should be transferred there (Minckley et al. 2003).

As part of our overall effort, it was necessary to contact several different agencies in order to collect rearing data. We suggest standardized tracking sheets (an example is provided in Appendix 26) to be used as part of a "chain of custody" maintained in a log book to follow a year class of fish from spawning to stocking, and in between the many facilities that a single year class of fish may reside. Piper et al. (1982) also presents various forms for tracking fish on and off station, while something similar is already in use at Dexter NFH & TC. We suggest this for both manual and volunteer-spawned bonytail at Dexter NFH & TC, and when eggs or fish are transferred off station, copies of the log will go to the new stations, which will start new year class log sheets as well as production rearing sheets (Appendix 27). We also suggest two repositories for all Colorado River basin fish, whether PIT or wire tagged, perhaps one each for upper and lower basins. The two basins would receive copies of the logs sheets from their respective facilities and annually exchange their information so managers and others have ready access to a consolidated data set on production, stocking and other distributions.

When we asked if facilities shared information with one another, some mentioned that they did while others mentioned that they did not. We recommend that this practice change to full disclosure and open dialogue, beginning with a proposed bonytail and razorback sucker rearing workshop in 2007 at which all facilities managers and staff can meet to discuss rearing practices, particularly what works and what has not.

LITERATURE CITED

Badame, P.V. and J.M. Hudson. 2003. Reintroduction and monitoring of hatchery-reared bonytail in the Colorado and Green Rivers, 1996-2001. Utah Division of Wildlife Resources, Salt Lake City. 54 pages.

Bolliet, V., M. Azzaydi and T. Boujard. 2001. Chapter 10. Effects of feeding time on feed intake and growth. Pages 233-249 in D. Houlihan, T. Boujard and M. Jobling, eds. Food Intake In Fish. Blackwell Publishing Limited, Oxford, England.

Bolliet, V., C. Cheewasedtham, D. Houlihan, A. Gelineau and T. Boujard. 2000. Effect of feeding time on digestibility, growth performance and protein metabolism in the rainbow trout, *Oncorhynchus mykiss*: interactions with dietary fat levels. Aquatic Living Resources 13(2): 107-113.

Boujard, T., A. Gelineau and G. Corraze. 1995. Time of a single daily meal influences growth performance in rainbow trout, *Oncorhynchus mykiss* (Walbaum). Aquaculture Research 26: 341-349.

Burke, T. 2006. Lower Colorado River Multi-Species Conservation Program Draft Fish Augmentation Plan. Bureau of Reclamation, Boulder City, Nevada. 15 pages.

Burdick, B.D. and R.L. Hamman. 1993. Study to evaluate several tagging and marking systems for Colorado squawfish, razorback sucker, and bonytail. Final report. U.S. Fish & Wildlife Service. 56 pages.

Chart, T.E. and S.J. Cranney. 1993. An evaluation of hatchery-reared bonytail chub (*Gila elegans*) released in the Green River, Utah, 1988-1989. Publication number 93-12. Utah Division of Wildlife Resources, Salt Lake City. 72 pages.

Czapla, T.E. 2002. Facilities plan for the production of endangered fishes to meet state stocking plans as part of the Upper Colorado River Endangered Fish Recovery Program. U.S. Fish & Wildlife Service, Region 6, Denver, Colorado. 9 pages.

Devine, G. 1995. Lower Colorado River basin studies, native fish species. Recovery/conservation program needs. July 17, 1995. American Rivers, Southwest Regional Office, Phoenix, Arizona. 3 pages.

Escandon, A.E.T. 1994. Morphological and physiological aspects of swimming performance among three cyprinid fishes: arroyo chub, *Gila orcutti*, bonytail chub, *Gila elegans*, and fathead minnow, *Pimephales promelas*. Doctoral dissertation, University of California, Los Angeles. 123 pages.

Gustaveson, W. and Q. Bradwisch. 2002. Operation and maintenance of Wahweap State Fish Hatchery, Utah. Annual report. Utah Division of Wildlife Resources, Page, Arizona. 4 pages.

Hamman, R.L. 1982. Induced spawning and culture of bonytail chub. Progressive Fish Culturist 44(4): 201-203.

Hansen, S.P., A. Choudhury, D.M. Heisey, J.A. Ahumada, T.L. Hoffnagle and R.A. Cole. 2006. Experimental infection of the endangered bonytail chub (*Gila elegans*) with the Asian fish tapeworm (*Bothriocephalus acheilognathi*): impacts on survival, growth and condition. Canadian Journal of Zoology 84: 1383-1394.

Henne, J.P., M.M. Romero, T.V. Martinez, B.M. Fillmore, A.L. Grannam and G.J. Carmichael. 2006. Performance of endangered bonytails fed four commercial diets. North American Journal of Aquaculture 68: 217-223.

Karlsen, O., G.I. Hemre, K. Tveit and G. Rosenlund. 2006. Effect of varying levels of macro-nutrients and continuous light on growth, energy deposits and maturation in farmed Atlantic cod (*Gadus morhua L.*). Aquaculture 255: 242-254.

Marsh, P. C., C. A. Pacey, and B. R. Kesner. 2003. Decline of the razorback sucker in Lake Mohave, Colorado River, Arizona and Nevada. Transactions of the American Fisheries Society 132: 1251-1265.

Marsh, P.C., C.A. Pacey and G. Mueller. 2005. Bibliography of Native Colorado River Big Fishes. U.S. Geological Survey, Denver, Colorado and Arizona State University, Tempe. 1515 KB (compact disc).

Minckley, W.L., P.C. Marsh, J.E. Deacon, T.E. Dowling, P.W. Hedrick, W.J. Matthews and G. Mueller. 2003. Conservation plan for native fishes of the lower Colorado River. Bioscience 53(3): 219-234.

Mueller, G.A. 2006. Ecology of bonytail and razorback sucker and the role of off-channel habitats in their recovery. U.S. Geological Survey, Scientific Investigations Report 2006-5065. 64 pages.

Mueller, G.A., J. Carpenter and P.C. Marsh. 2005. Cibola High Levee Pond annual report 2004. U.S. Geological Survey, Fort Collins Science Center, Colorado, and Arizona State University, Tempe. 23 pages.

Noeske-Hallin, R.E. Spieler, N.C. Parker and M.A. Suttle. 1985. Feeding time differentially affects fattening and growth of channel catfish. The Journal of Nutrition 115(9): 1228-1232.

Paukert, C.P., D.L. Ward, P.J. Sponholtz and K.D. Hilwig. 2005. Effects of repeated hoop netting and handling of bonytail chub. Journal of Freshwater Ecology 20(4): 649-653.

Pavlidis, M., G. Koumoundouros, A. Sterioti, S. Somarakis, P. Divanach and M. Kentouri. 2000. Evidence of temperature-dependent sex determination in the European sea bass (*Dicentrarchus labrax L.*). Journal of Experimental Zoology 287: 225-232.

Piper, R.G., I.B. McElwain, L.E. Orme, J.P. McCraren, L.G. Fowler and J.R. Leonard. 1982. Fish Hatchery Management. U.S. Fish & Wildlife Service, Washington, D.C. 517 pages.

Robinson, E.H., L.S. Jackson, M.H. Li, S.K. Kingsbury and C.S. Tucker. 1995. Effect of time of feeding on growth of channel catfish. Journal of the World Aquaculture Society 26(3): 320-322.

Snyder, D.E. 1981. Contributions to a guide to the cypriniform fish larvae of the upper Colorado River system in Colorado. Colorado State University, Department of Fishery and Wildlife Biology, Fort Collins. 81 pages.

Stickney, R.R. 1993. Introduction. Pages 1-32 in R.R. Stickney, ed. Advances in Fisheries Science. Culture of Nonsalmonid freshwater fishes. CRC Press, Boca Raton, FL.

Tyus, H.M. 1988. Protocol for the handling and transport of wild bonytail in the upper Colorado River basin. U.S. Fish & Wildlife Service, Vernal, Utah. 4 pages.

U.S. Fish & Wildlife Service. 1980. Bonytail chub; determination as an endangered species. Federal Register 45(80): 27710-27713.

U.S. Fish & Wildlife Service. 2006. Dexter National Fish Hatchery & Technology Center monthly accomplishment report, May 2006. U.S. Fish and Wildlife, Dexter National Fish Hatchery and Technology Center, Dexter, NM. 5 pages.

Ward, D.L. 2003. Effects of marking techniques and handling on swimming ability of bonytail chub. Journal of the Arizona Nevada Academy of Science 36(1): 34-36.

Wydoski, R.S. 1994. Coordinated hatchery facility plan: need for captive-reared endangered fish and propagation facilities. U.S. Fish & Wildlife Service, Denver, Colorado. 133 pages.

PERSONAL COMMUNICATIONS

Willow Beach NFH staff. Willow Beach NFH, U.S. Fish & Wildlife Service, Willow Beach, AZ. August 2006 – meeting.

Webber, Grant. Manager. Uvalde NFH, U.S. Fish & Wildlife Service, Uvalde, TX. September 2007 – meeting.

Nelson, Chris. Manager, sales and service. Nelson & Sons, Inc., Murray, UT. December 2006 – telephone.