POPULATION STATUS OF THE ENDANGERED MOHAVE TUI CHUB (*SIPHATELES BICOLOR MOHAVENSIS*) AT LAKE TUENDAE, ZZYZX, CALIFORNIA

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By

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ABSTRACT

The endangered Mohave tui chub *(Siphateles bicolor mohavensis)* historically inhabited the Mojave River system in the Mojave Desert of California. Although these fish were eliminated from the Mojave River, via introduced species and habitat degradation, the species survived in an isolated natural spring. This population was used to stock recovery populations, of which three persist to date. This research documents current population size, structure, and trends of the Lake Tuendae population. Lake Tuendae has experienced a perennial plankton bloom beginning in 2003, following a dredging project, and an unauthorized introduction of mosquito fish. In addition, fish are infected with the introduced Asian tapeworm (*Bothriocephalus acheilognathi*). In April and October of 2004 and October 2005 mark and recapture surveys of Mohave tui chub were conducted at Lake Tuendae. The population size was estimated using the Schnabel method to be 2,241 (95% C.I.: 2,090-2,416) in April 2004, 3,708 (95% C.I.: 3,539-3,894) in October 2004, and 3,354 (95% C.I.: 3,213-3,509) in October 2005. Length frequency distributions also indicate successful juvenile recruitment. In addition, lengths and weights were compared to populations at Camp Cady and China Lake. This research provides baseline data to aid in developing long-term monitoring plans. While the Lake Tuendae population is not rapidly declining, further studies are needed to determine the effects introduced species and habitat conditions will have on this endangered fish.

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Note: The two spellings of Mojave and Mohave reflect different origins of the word. The spelling of Mojave reflects the Spanish derivation and Mohave reflects the Indian derivation. Mohave tui chub is derived from the Paiute Indians, who named this fish "tui-pagwi", where "pagwi" is the Paiute word for minnow (Bolster, 1996).

This thesis is dedicated to my father, Alex Garron, to which words cannot express my love and gratitude. Through his care and patience, he has opened my eyes to the beauty of nature and inspired an appreciation for the natural world around me. Thank you.

CHAPTER 1

INTRODUCTION

During the Pleistocene epoch, the western interior basins of the southwestern United States were filled with pluvial lakes (Smith, 1981; Brown and Lomolino, 1998) (Figure 1). As the climate began to change during the Holocene, these vast lakes began to disappear. As a result, the fish fauna of the time either found refuge in remnant pools and streams or became extinct. Isolated aquatic refugia led to vicariant speciation of these fishes (Brown and Lomolino, 1998). North American deserts now contain various rare or endangered endemic desert fish species and subspecies that are important relics of geologic time. The distribution of these fishes and their phylogenetic relationships provide information of past geologic conditions and offer examples of evolution and speciation (Miller, 1946; Smith, 1981).

Recent years have shown dramatic declines in the aquatic faunas in western North America (Moyle and Williams, 1990). A major threat to aquatic environments occur in these regions where precipitation levels are naturally low, and continuous population growth has resulted in increased demands on ground-water basins (Smith, 2003). As a result, the construction of dams and reservoirs alter natural water regimes and subsequently, aquatic environments. The decline of native fish faunas has also been

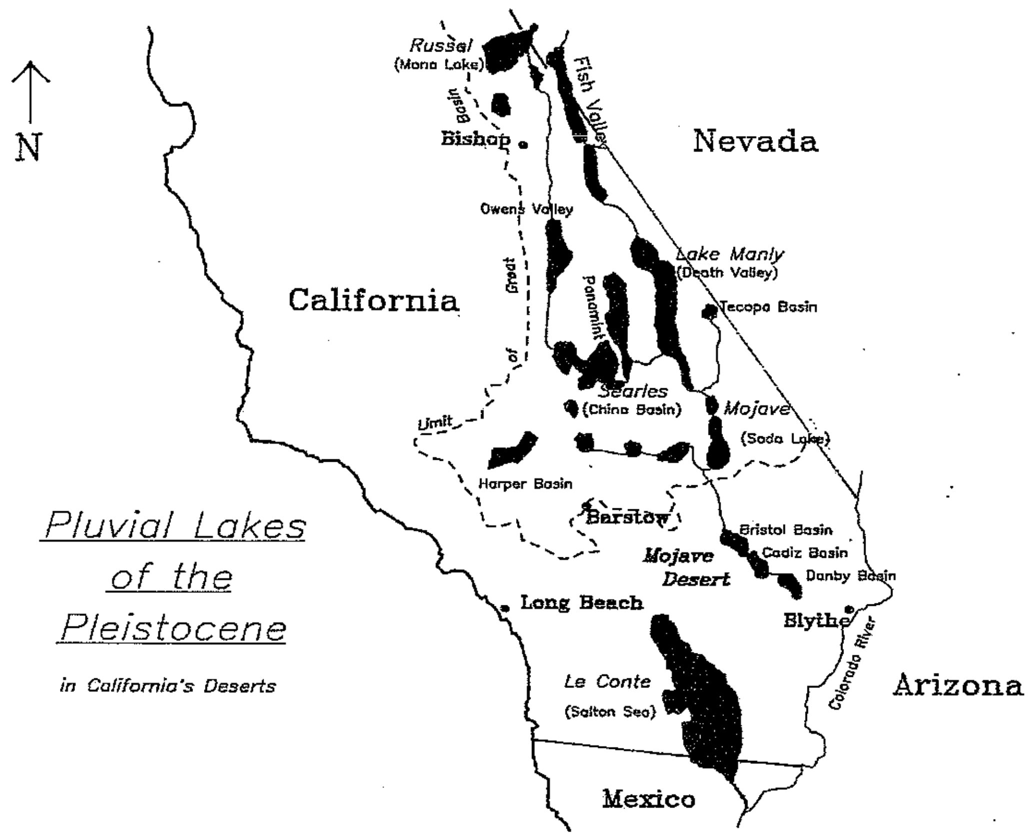

Figure 1. Distribution of Pluvial Lakes during the Pleistocene in California's Deserts (Taken from map collection at The Desert Studies Center, Zzyzx, California).

attributed to poor land use, introduced species, and over-fishing of some species (Moyle, 1995).

Tui chubs, which belong to the minnow family (Cyprinidae), were a part of the fish fauna that inhabited the pluvial lakes of the late Cenozoic (Smith, 1981). As these great lakes receded, various distinct forms of tui chub were established amid the isolated drainages of the region. Among these, the closely related Mohave tui chub (*Siphateles bicolor mohavensis*), of the Mojave River drainage, and the Owens tui chub (*S. b. snyderi*), of the Owens Basin, are relatives of chubs from the Lahontan area and derived from earlier drainage connections between these basins (Smith, 1981). Distribution of the Mohave tui chub during the Pleistocene extended throughout the Mojave River drainage, which probably supported a rich population of Mohave tui chubs (Hubbs and Miller, 1943).

In the Mojave Desert, the headwaters of the Mojave River begin at the junction of West Fork and Deep Creek at the northern foot of the San Bernardino Mountains (Lines, 1996). The Mojave River runs northeast for approximately 200 km into the desert (Lovich and Meyer, 2002). Although mainly a subterranean river, it does surface occasionally along its course. After emerging in Afton Canyon, the river splits into two separate channels. These channels terminate in East Cronese Dry Lake and Soda Dry Lake, respectively. The river has been known to flood these dry lakes, or playas, after extreme storms (Lines, 1996).

Mohave tui chub historically inhabited the Mojave River but are now restricted to a few refugia within the Mojave Desert. Sometime before the 1930s, the related arroyo chub (*Gila orcutti*) was introduced into the Mojave River as baitfish (St. Amant and Sasaki, 1971; USFWS, 1984). Arroyo chub are native to coastal streams of southwestern California (Miller, 1968). The arroyo chub readily hybridized with the Mohave tui chub (Hubbs and Miller, 1943). Studies have also shown that Mohave tui chub are more associated with lake environments, having only relatively recently been constrained to the Mojave River; while the Arroyo chub, long inhabiting stream environments, were able to out-compete Mohave tui chubs (Castleberry and Cech, 1986; McClanahan et al., 1986). By the 1960s, genetically pure Mohave tui chubs were eliminated from the Mojave River system (Castleberry and Cech, 1986; McClanahan et al., 1986). Habitat degradation has also been noted to contribute to the decline of *S. b. mohavensis* (USFWS, 1984).

For these reasons, the Mohave tui chub was listed as endangered by the United States Fish and Wildlife Service (USFWS) in 1970, and by the California Department of Fish and Game (CDFG) in 1971 (Woo and Hughson, 2003). In the 1984 Mohave Tui Chub Recovery Program Report, the USFWS outlined management plans to remove this species from the list of threatened and endangered wildlife. This included the establishment of six stable populations of at least 500 fish each, located within the historic range of the species. In addition, recovery efforts were expected to require frequent monitoring and continuous management of extant populations to ensure adequate protection.

Mohave tui chub survived displacement from the Mojave River in Mohave Chub Springs (MC Springs), a small natural spring found on the western edge of the dry Soda Lake Bed. Mohave tui chub were possibly able to establish this population as a result of the river flowing into Soda Lake during the 1916 and 1938 flood years or may have been transplanted there (May and Agresti, 1997). Genetic studies indicate these chubs are genetically pure *S. b. mohavensis* (May and Agresti, 1997). This relictual population was used to stock numerous recovery populations, most of which have failed to become established (Hoover, 1983).

Three populations of Mohave tui chub persist to date:

1) China Lake Naval Air Weapons Station (NAWS)

In 1971, 425 Mohave tui chub were transplanted from MC Springs into Lark Seep at the China Lake NAWS (Woo and Hughson, 2003). The City of Ridgecrest's Waste Water Treatment Facility evaporation and percolation ponds have been located on the China Lake NAWS since 1945 (NAWS, 2002). These ponds increased already high ground water levels and resulted in the development of Lark Seep. A system of channels was created (G1 Channel, George Channel, and North Channel) to move water flow away from nearby facilities out to the China Lake playa, where G1 Seep formed (NAWS, 2002). Since their introduction, it is presumed that Mohave tui chub have been able to migrate into G1 Seep, since they have been recorded in all channels. Population size has been estimated at China Lake, but low recapture rates have resulted in large confidence intervals (NAWS, 2002). The Mohave tui chub share this habitat with the exotic mosquito fish (*Gambusia affinis*) and common carp (*Cyprinus carpio*).

2) Camp Cady Wildlife Area

Camp Cady Wildlife Area, located in the Mojave River drainage, is managed by the California Department of Fish and Game (CDFG). Mohave tui chub were introduced into two artificial ponds circa 1986 when the ponds were excavated (Woo and Hughson, 2003). One of these ponds, the east pond, has since dried up seemingly due to unidentified leaks or cracks in the clay lining. The west pond (55 x 35.5 m) continues to support a population of *S. b. mohavensis*. Mohave tui chub are the only fish known to inhabit the west pond.

3) Desert Studies Center

At the Desert Studies Center, Mohave tui chub inhabit both Lake Tuendae and MC Springs. These are considered one population since the two habitats occur in the same area (UFWS, 1984). Lake Tuendae, an artificial pond (150 m x 40 m; 0.5-2 m deep) (USFWS, 1984), was excavated circa 1955 by Curtis Howe Springer. Springer established the Zzyzx Mineral Springs and Health Resort at Soda Springs in 1944 (Woo and Hughson, 2003). This area is now the Desert Studies Center under the California State University Consortium. Mohave tui chub were most likely transplanted from MC Springs to Lake Tuendae by Springer or his associates (Woo and Hughson, 2003). Lake Tuendae provides habitat for Mohave tui chub, as well as the Saratoga Springs pupfish (*Cyprinodon nevadensis nevadensis*) and the non-native mosquito fish (*Gambusia affinis*) (Turner and Liu, 1976; Woo and Hughson, 2003).

Due to accumulation of sediments and cattails, Lake Tuendae must be dredged about every 10 years (Woo and Hughson, 2003). During a dredging in Fall 2001, some fish were accidentally killed and upon analysis were reported to be infected with Asian tapeworm (*Bothriocephalus acheilognathi*). Asian tapeworm can be detrimental to fish populations, and is known to negatively effect cyprinids (Salgado-Maldonado and

Pineda-Lopez, 2003). Studies on other fish species have shown this tapeworm to significantly reduce survivorship of those infected (Granath and Esch, 1983). At high infection levels, *B. acheilognathi* may cause serious injury to fry and small fish. This tapeworm may cause blockage in the intestines and create lesions on the intestinal wall, causing most infected fishes to have distended stomachs. Infection may also cause reduced growth and reproduction, and ultimately increased mortality (Granath and Esch, 1983; Salgado-Maldonado and Pineda-Lopez, 2003). The exact effects of this tapeworm on tui chub are unknown.

During this dredging it was also discovered that Lake Tuendae had suffered an unauthorized introduction of mosquito fish. Introductions of mosquito fish have been shown to negatively affect other native fish populations (Mills et al., 2004). Mosquito fish are aggressive predators that feed on smaller fish, including their own species, and have been known to out-compete native fishes. Overall, presence of mosquito fish has been correlated with the decline of native species (Mills et al., 2004). In addition, a plankton bloom in 2003 has raised concerns over the condition of the lake and the subsequent effects on resident fish.

To provide adequate protection for this endangered species, established populations and habitat conditions should be assessed and monitored regularly (USFWS, 1984; Bolster, 1996). Recent concerns only underscore the importance of continuous assessment for this population. The introduced Asian tapeworm could have detrimental effects that may otherwise go undetected. Unstable water quality and introduced mosquito fish could also have negative impacts. The objectives of my study are to; 1) establish the population status of Mohave tui chub at Lake Tuendae; 2) determine if there is evidence of successful juvenile recruitment; and 3) to provide baseline data to aid in developing long-term monitoring plans. These data may also be used to aid in possible establishment of other recovery populations and future management decisions in the recovery efforts of this endangered species.

Biology of Mohave tui chub

Mohave tui chub are a moderate sized fish. In 1943, Hubbs and Miller measured Mohave tui chub ranging from 52-92 mm in standard length, from collections at Deep Creek, located near the headwaters of the Mojave River. Standard length (SL) is measured from the tip of the snout to the posterior end of the hypural bone (Anderson and Gutreuter, 1983). Adults often reach lengths of 150 mm SL (USFWS, 1984), but have been recorded as large as 215 mm SL (Vicker, 1973). Mohave tui chub are usually described as having chunky or thick bodies with a large head that begins to establish a concave profile as the fish grows. A pronounced hump may also develop behind the head in larger fish (USFWS, 1984; Moyle, 2002). They have a short snout with a small terminal mouth that is slightly angled downward and does not extend to the eye (Moyle, 2002). Their large shield-shaped scales are lighter in the center with darker boarders (Hubbs and Miller, 1943; USFWS, 1984). They are brassy-brown to dusky olive dorsally, gold and finely speckled laterally and bluish white to sliver ventrally (Hubbs and Miller, 1943; USFWS, 1984; Bolster, 1996). They have small rounded fins that are olive to rich brown while lower fins pale outward with a bluish to white boarder (Hubbs and Miller, 1943; USFWS, 1984). Males and females display no obvious sexual dimorphism.

Mohave tui chub were historically found in deep pools and prefer deeper, cooler, slow-moving waters (Castleberry and Cech, 1986; McClanahan et al., 1986). Aquatic vegetation is needed for egg attachment and is also used for thermal refuge and protection from predators (USFWS, 1984). Mohave tui chub can tolerate high levels of salinity, low levels of dissolved oxygen (DO), and have an upper thermal maximum near 34°C (Castleberry and Cech, 1986; McClanahan et al., 1986). But in comparison to most desert fishes, which can tolerate extreme fluctuations in environmental conditions, Mohave tui chub are relatively sensitive to physical factors such as temperature, flow rate and salinity (McClanahan et al., 1986). This can be attributed to a relatively recent ancestry inhabiting large open lakes (Castleberry and Cech, 1986). In the winter, Mohave tui chub become inactive; in bottom seine hauls during December and January, Vicker (1973) only found few chub, which appeared to be in a torpid state.

Mohave tui chub first spawn at one year of age and spawning begins in February, reaching a maximum by the start of April, and declines in May; spawning may resume in early fall (Vicker, 1973). Spawning occurs over aquatic vegetation where eggs, about 1 mm in diameter, are attached to the vegetation and hatch in 6-8 d at 18-20°C (USFWS, 1984). In Owens tui chub, a close relative of Mohave tui chub, larvae grow quickly during their first summer (Leunda et al., 2005). Also, Owens tui chub have been reported to grow continuously during the first two years of development (DFC, 1996). Overall, growth for Mohave tui chub has been reported to occur most rapidly from May to July

(Taylor and McGriff, 1985). Fry form small schools in shallow areas. Moderate-to large-sized fish tend to school in deeper waters, while the largest fish are usually solitary and found in the deepest waters (USFWS, 1984).

Mohave tui chub most probably feed on plankton, insects, and organic debris. Vicker (1973) analyzed the stomach contents of 60 Mohave tui chub, which consisted primarily of waste food thrown into the lake by guests of the Zzyzx Mineral Springs Resort. A small volume of identifiable food sources included insect eggs and larvae, and plant debris.

CHAPTER 2

METHODS

Mohave tui chub (*Siphateles bicolor mohavensis*) were sampled from Lake Tuendae at the Desert Studies Center, located in the Mojave National Preserve, San Bernardino County; the West Pond at the California Department of Fish and Game's Camp Cady Wildlife Area, San Bernardino County; and at George Channel and G-1 Channel located at the China Lake Naval Air Weapons Station, Kern County (Figure 2). All of these populations are located in the Mojave Desert of California.

Lake Tuendae

Three trapping periods were conducted at Lake Tuendae, hereafter the lake: April 28-30, 2004; October 20-21, 2004; and October 18-20, 2005. The same trapping methods were used in October 2004 and 2005, but the methods in the first trapping period, April 2004, were different, as described below. April trap data were used to standardize the subsequent trapping methods.

April Trapping Methods.

A total of 84 traps, of five different types, were used during this trapping period (Table 1). The lake was divided into four quadrants. Trap type and amount were divided among each quadrant (Table 2). Trapping stations were set up around the lake, with two traps per station (Figure 3). Station 1 was just west of the concrete pad in the middle of

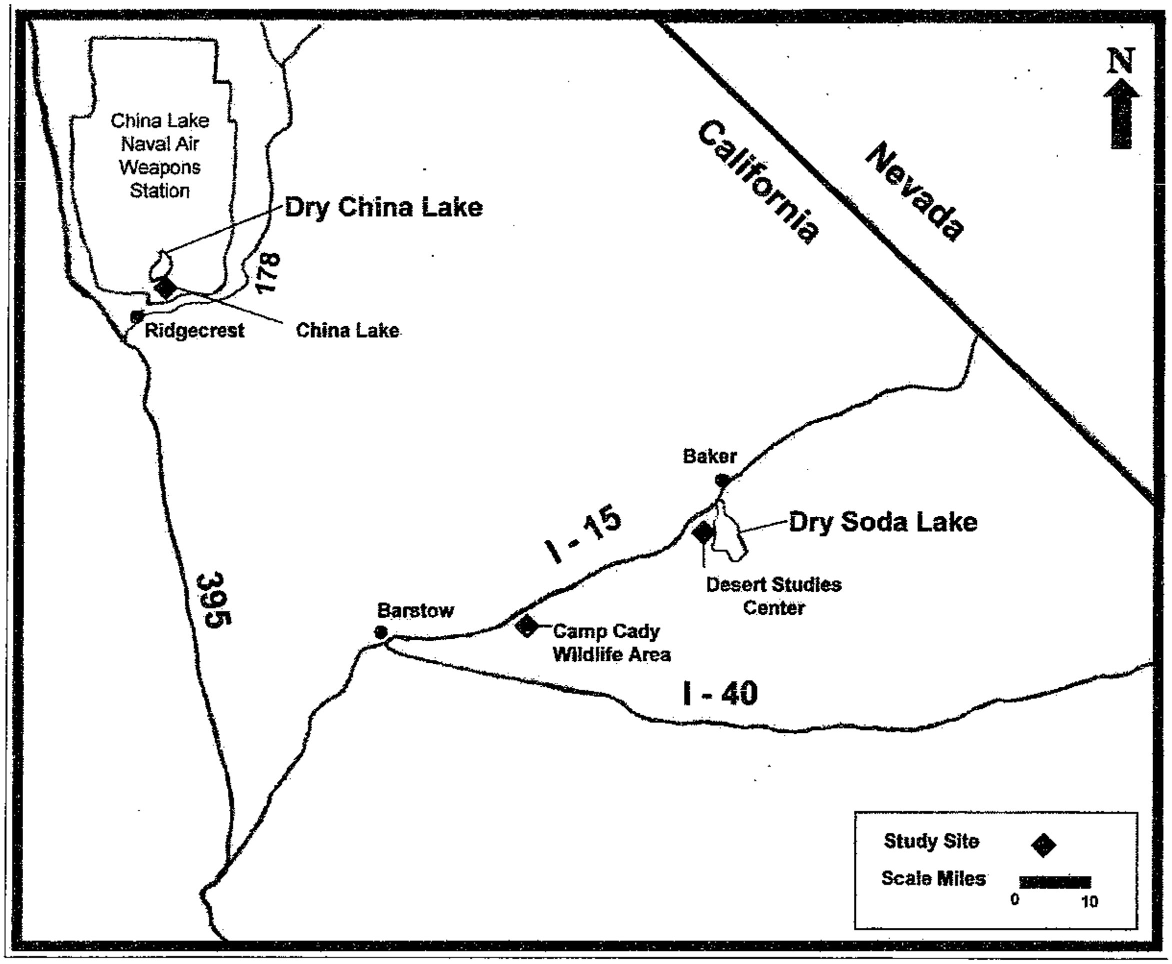

Figure 2. Map of study sites; Lake Tuendae at the Desert Studies Center, located in the Mojave National Preserve, San Bernardino County; California Department of Fish and Game's Camp Cady Wildlife Area, San Bernardino County; and China Lake Naval Air Weapons Station, Kern County; all located within the Mojave Desert of California.

Table 1. Type of trap and trap measurements for traps used in the April 2004 trapping of Mohave tui chub at Lake Tuendae.

Trap Type	Total Number of Traps	Mean Opening Size (mm)	Mesh Size (mm)
Standard Minnow	41	24 x 24	6 x 6
Extended Minnow	19	50 x 50	6 x 6
Large minnow	13	64 x 43	13 x 13
Square-1-Hole	4	35 x 35	12 x 25
Squre-2-Hole	7	108 x 24	12 x 27

Table 2. For the April 2004 trapping design, traps were distributed among Lake Tuendae by dividing the Lake into four quadrants (Figure 3). Traps were divided among quadrants. Number of traps and trap-type are displayed per quadrant.

Quadrant	Trap Stations	Trap Type	Number
1	1-12	Standard Minnow	10
		Extended Minnow	5
		Susan	3
		Square 2-hole	2
		Square 1-hole	1
2	13-22	Standard Minnow	11
		Extended Minnow	4
		Susan	4
		Square 2-hole	1
		Square 1-hole	1
3	23-33a	Standard Minnow	10
		Extended Minnow	5
		Susan	3
		Square 2-hole	2
		Square 1-hole	1
4	33b-43	Standard Minnow	11
		Extended Minnow	4
		Susan	4
		Square 2-hole	1
		Square 1-hole	1

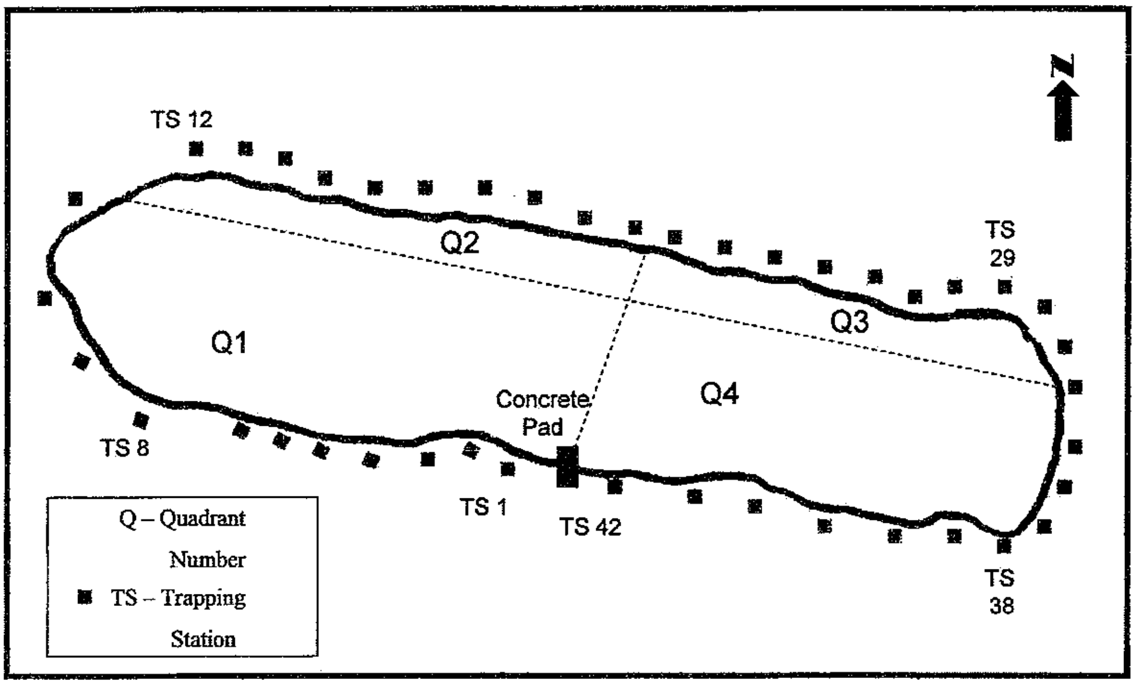

Figure 3. Trap station distribution per quadrant, during the Lake Tuendae, April 2004 trapping period. Each trapping station had two traps.

the south shore; stations were numbered sequentially around the lake with station 42 ending just east of the concrete pad. Traps remained at the assigned trapping station for the duration of the sampling.

Five individual samples were collected in the 3-d period. For each sample, all traps were deployed at approximately the same time. After a 3-h period, traps were removed from the water beginning at station 1, moving sequentially around the lake to station 42. Depending on the catch in each trap and time to process the total catch, total fishing time for each trap varied. Traps were baited with bread for sample number 4 only, and only the large minnow traps were used for this sample.

As traps were removed from the water, captured fish were placed in a holding bucket filled with lake water. Fishes were individually removed from the holding bucket and processed. Mohave tui chub were measured in total length (mm), which measures the most anterior part of the fish (tip of the snout or mouth) to the edge of the longest caudal fin rays (Anderson and Gutreuter, 1983). Fish were marked, if previously unmarked, by clipping the right pelvic fin. Fish that were < 70 mm in total length were not marked. Any pupfish (*Cyprinodon nevadensis nevadensis*) which were incidentally captured were also measured in total length (mm). Fishes were then placed in a recovery bucket of lake water, and returned to the lake after a recovery period. Any mosquito fish (*Gambusia affinis*) which were incidentally captured were also measured in total length (mm) and removed from the lake.

<u>April trap analyses.</u> Trap type capture success was compared using a catch per unit effort estimation procedure. Captures for each trap type was standardized by taking

the number of fish captured over the number of traps of that trap type. This was then divided by the total hours each trap type was operational. Histograms were also constructed for each trap type to determine the distribution of the size classes of fish that each type of trap captured.

Capture success was also determined for each type of trap used. This analysis compared the amount of total fish captured among the five trap types, based on a proportion to account for the different number of traps of each type. If all traps captured fish equally, then the expected frequency of captures for each trap type would be equal to the proportional representation of each trap type. This was calculated as the expected number of captures. The expected value was statistically compared to the actual number of captures using a Chi-square test. Sample 4 deployed only large minnow traps and was therefore excluded from this analysis.

October Trapping Methods

The trapping design was the same for both October 2004 and October 2005 trapping periods. A total of 30 traps were used in the trapping design, with two different types of traps (Table 3). These two trap types were the standard minnow and large minnow traps. Thirteen large minnow traps, which had the same measurements from April 2004, were used. Seventeen standard minnow traps were modified to have a larger opening, with a mean of 42 x 35 mm, labeled the modified standard minnow trap.

Along both the north and the south shore of the lake, 15 trapping stations were set 10 m apart, for a total of 30 trapping stations (Figure 4). Trapping stations were numbered with station one located at the southeast corner; traps on the south shore were

Table 3. Type of trap and trap measurements for traps used in the October 2004 and October 2005 trapping of Mohave tui chub at Lake Tuendae.

Trapping Period	Trap Type	Total Number of Traps	Mean Opening Size (mm)	Mesh Size (mm)	Length of Trap (cm)	Width of Trap (cm)
October 2004	Modified standard minnow	17	42 x 35	6 x 6	41.3	21.9
	Large minnow	13	50 x 35	13 x 13	61.6	33.0
October 2005	Modified standard minnow	17	65 x 49	6 x 6	41.3	21.9
	Large minnow	13	50 x 35	13 x 13	61.6	33.0

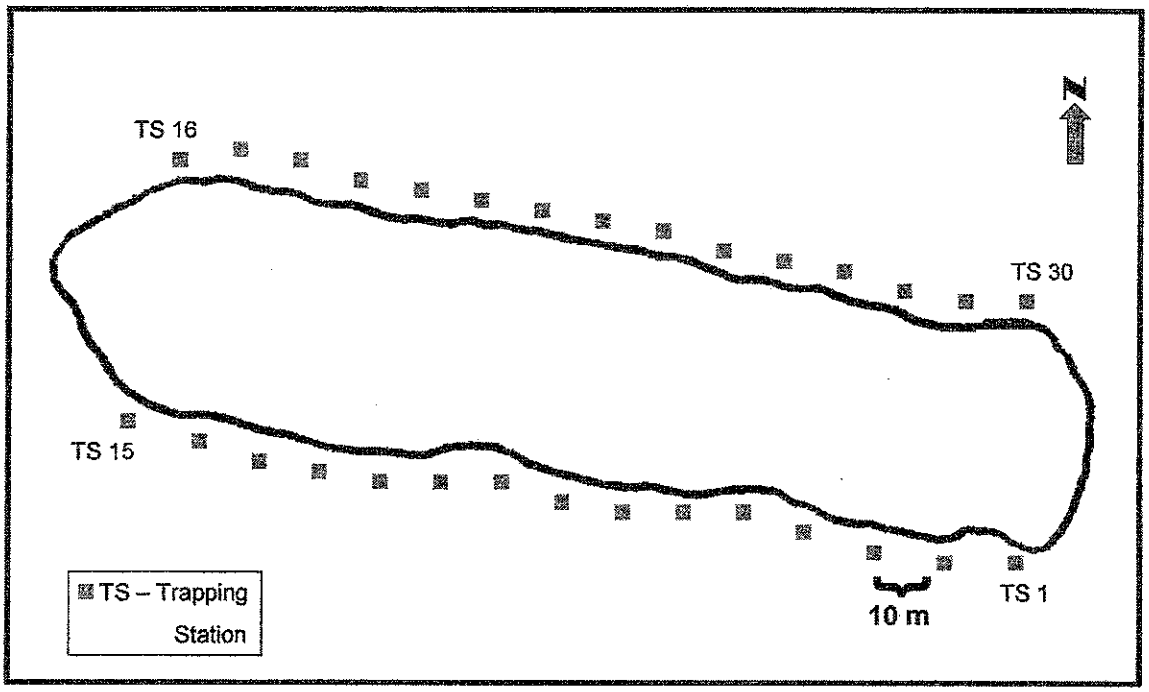

Figure 4. Map displaying trap station distribution around Lake Tuendae for the October 2004 and 2005 trapping periods.

numbered 1-15 and the north shore were stations 16-30. Trap distributions were determined so that one shore had seven large minnow traps and eight standard minnow traps distributed among the 15 stations, while the other shore had six large minnow traps and nine standard minnow traps distributed among the 15 stations. It was randomly determined before each sample which shore received which distribution.

The locations of the traps relative to the shore were also randomly determined for each sampling period. Each trap was attached to a 22-m cord that was marked at 10 m. Traps were thrown into the water at the bank of the shore, approximately 10 m out from the bank (labeled as a quarter distance out into the lake) or placed via rowboat 22 m toward the middle of the lake. Anchored from each shore, six traps were located at the bank of the lake, six traps a quarter distance out (10 m) and three in the middle of the lake (22 m). Therefore a total of six traps, three anchored from each shore, were fishing in the middle of the lake for each sample (Figure 5). Before each sample, the trap type and distance of each trap from shore was randomly determined per station.

For each sample, all traps were baited with bread and were operational approximately 2-h. The first trap to be pulled and which direction to proceed around the lake was randomly determined as well. Depending on total catch, collection times differed at each station, therefore total fishing time per trap varied. A total of six samples were conducted in the 2-d period during the October 2004 trapping period and a total of five samples were conducted in a 3-d period during the October 2005 trapping period. Temperature, pH, and dissolved oxygen were also recorded during the October 2005 samples. Fish captured were processed in the same procedure for the April trapping

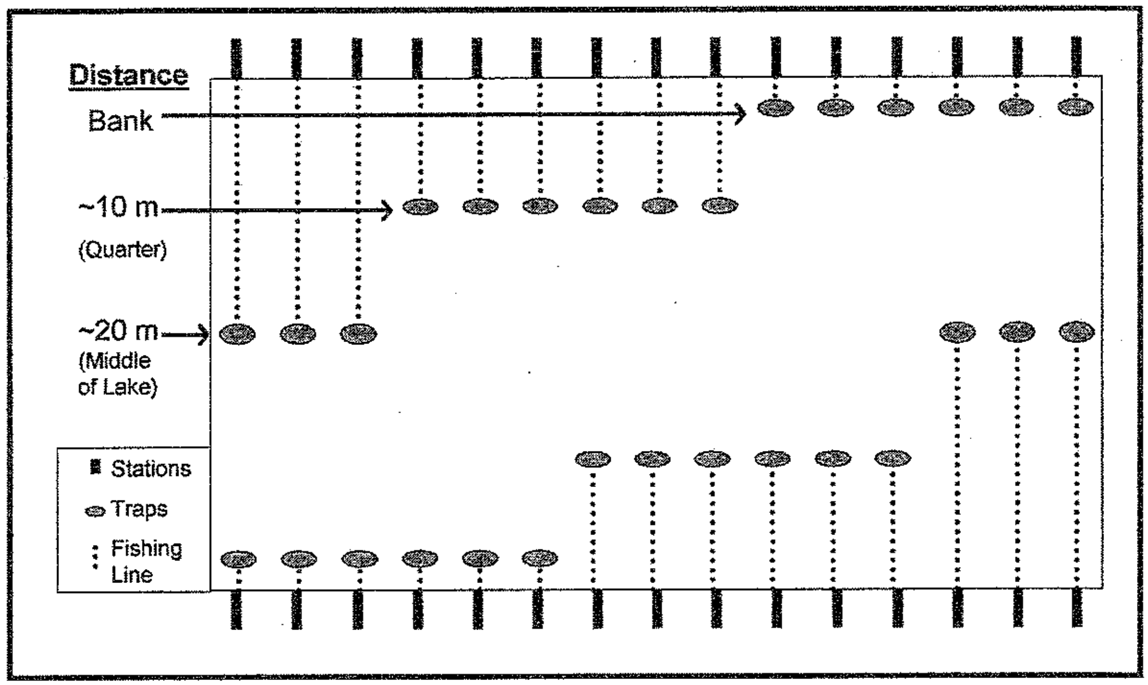

Figure 5. Schematic for trap layout in Lake Tuendae for both the October 2004 and 2005 trapping designs; placement of trap in Lake (bank, quarter, or middle) and type of trap (modified minnow or large minnow) was randomly determined per trap station per sample. Therefore, actual positions of traps varied depending on randomization determined at the beginning of each trap run.

methods, except that the left pelvic fin was marked. Any pupfish or mosquito fish that were incidentally captured were accounted for, but not measured. Pupfish were returned to the lake at location of capture.

An electronic balance was used to weigh selected Mohave tui chub during the October 2004 trapping period. Weights were determined with an electronic balance to the nearest gram for some individuals captured during samples 3 and 4. The highest weight capacity of the balance was 200 g. Weights of five individuals exceeded this capacity.

October trap analyses. Capture success was determined for each type of trap used. This analysis compared the amount of total fish captured among the two trap types, based on a proportion to account for the different amount of traps per trap type. If all traps were capturing fish equally, then the expected number of captures for each trap type would be equally distributed based on the number of traps available. This was calculated as the expected number of captures. The expected value was statistically compared to the actual number of captures per trap type using a Chi-square test.

Length-weight Relationships

Length-weight relationships were determined for total length (mm) and weights (g) that were collected during the April 2004 and October 2004 trapping periods. The length-weight relationship was determined by the equation

$$W = aL^b \qquad \text{(Equation 1)}$$

where W = weight, L = length, and a and b are determined by the slope parameters from the linear regression, using the $\log_{10}$ of the length and the $\log_{10}$ of the weight. The coefficients *a* and *b* describe the proportional growth relationships (Jobling, 2002). As the fish grows, body shape changes as length increases, *b* denotes how these growth changes relate to each other. A *b* value of 3.0 indicates isometric growth, i.e., both length and weight is increasing proportionately. Allometric growth is indicated if b is > 3.0 or < 3.0. When b is > 3.0, weight is increasing more rapidly than the length. When b is < 3.0, length is increasing more rapidly than weight (Jobling, 2002).

Length-frequency Distributions

Total length (mm) distribution, in 10-mm increments, was compiled in a frequency histogram. Frequency was calculated as the percentage of total fish captured in the specific length cohort or class. Length frequency histograms can indicate population dynamics over time. Fish tend to grow in spurts during optimal conditions and, subsequently, those hatched in the same year tend to have similar growth patterns (Jearld, 1983). The distribution of these cohorts can be followed progressively over time. Changes in the distribution of size classes may ultimately reflect recruitment, growth, or mortality (Jearld, 1983).

Catch Curves

Length data collected from Lake Tuendae was compared to data collected by Vicker (1973), who aged Mohave tui chub from Lake Tuendae using scale annuli. Lengths for these fish were measured in standard length (mm) while I measured total lengths (mm). Fish collected by Vicker (1973) were still among the collection of specimens belonging to Dr. Mike Horn at California State University, Fullerton. I measured both standard length and total length of these preserved specimens. The relationship between standard length and total length was analyzed by a general linear regression. The equation determined by this analysis could then be used to convert standard length values to total length. Length at age classes established by Vicker (1973) were compared with length measurements collected during this study. Taylor and McGriff (1985) also established age classes for Mohave tui chub at Lake Tuendae, using scale annuli. Taylor and McGriff (1985) reported size in standard lengths, which were converted to total length using the above regression to compare with my trapping results.

Catch curves were established using these age classes to estimate adult survival. A catch curve is the plot of the natural logarithm (ln) of the number of fish captured in each age group versus age (Smith, 1990). This produces a hump-shaped curve with the left, ascending limb representing younger age classes that were not adequately sampled by the gear (traps) used. As the curve descends, however, these age classes are known to be fully recruited. The slope of the descending limb yields an estimate of survivorship from one age class to the next. This procedure for estimating survival of adults makes the following assumptions: (1) the mortality rate is uniform with age; (2) mortality rate is constant over time; (3) samples are randomly taken from age groups; and (4) recruitment is constant over time (Krebs, 1989). Accepting these assumptions, the rate of survival was estimated from the antilog of the slope of the right limb of the catch curve, using the equation:

$$\hat{S} = e^{-I} \quad \text{(Equation 2)}$$

$\hat{S}$ = Annual survival rate
I = Instantaneous mortality rate

Using annual age classes established by Vicker, age classes were fit to current data. Catch curves were established for data collected for all trapping periods, for data collected by Vicker (1973), and for Taylor and McGriff (1985).

Population Estimate

For all trapping periods at Lake Tuendae, a mark-recapture approach was used to estimate population size. The Schnabel method, which is an extension of the simple Peterson method (Krebs, 1989) estimates population size ($\hat{N}$) using the equation:

$$\hat{N} = \frac{\sum (C_t M_t)}{\sum R_t} \qquad \text{(Equation 3)}$$

For each sample t:

C_t : Total number of individuals caught in sample t
M_t: Number of marked individuals in the population prior to t^{th} sample
R_t : Number of recaptures

The Schnabel method estimates population size for a closed population sampled over multiple recapture periods. This method has the same assumptions as the Petersen method: (1) the population is closed; (2) all individuals have an equal chance of capture for each sample; (3) marking individuals does not affect their catchability; (4) animals do not lose marks between samples; and (5) all marked individuals are recorded for each sample (Krebs, 1989). Recaptures were identified by presence of clipped fins.

Habitat Use

For both October trapping periods, capture success was determined for the trapping locations within the lake. Each trapping location was categorized as: the bank of the lake, a quarter distance from the bank (approximately 10 m from the bank), and the middle of the lake. If fish were equally distributed within the lake, then all locations would be capturing fish equally. This was calculated as the expected number of captures, based on a proportion to account for the different total trap number for each location. The expected value was compared to the actual number of captures at each location using a Chi-square test. The mean total length of fish captured at each location was also compared using a one-way analysis of variance (ANOVA). This tested if there was a statistical difference in mean total length among fish captured at the bank, quarter distance, and middle of the lake.

<u>Camp Cady</u>

The Mohave tui chub population in the west pond (55 x 35.5 m) at Camp Cady Wildlife Area was surveyed on 19 October, 2004. A total of five traps were used in the trapping design: three modified standard minnow traps and two large minnow traps. Traps were the same as those used during the Lake Tuendae October samplings. The modified standard minnow traps were set at the northwest corner, southeast corner, and at the middle of the south bank. The large minnow traps were set at the northeast corner and at the southwest corner. Traps were deployed once, roughly 8 m from the bank, and left fishing for approximately 3-h. Traps were pulled starting with the southeast corner, moving clockwise around the pond.

Traps were pulled from the pond and fish were placed in a holding bucket filled with pond water. Mohave tui chub were individually removed from the holding bucket, measured in total length (mm) and weighed (g). Fish were not marked. Fish were then placed in a recovery bucket of pond water. After the recovery period, fish were returned to the pond at the location of capture. No re-sampling was conducted.

China Lake Naval Air Weapons Station

The Mohave tui chub population at China Lake was surveyed at the George Channel on November 1 and 2, 2004 and at the G-1 Channel on November 3, 2004. Traps used in the China Lake sampling were the same traps used in the Lake Tuendae October sampling periods: modified standard minnow traps and large minnow traps.

A total of 31 traps were used at the George Channel: 18 modified standard minnow traps and 13 large minnow traps. Thirty-one trapping stations were set up along the channel. Stations were positioned approximately 12.2 m apart, with one trap per station. This channel is approximately 403 m long and ranges from 4.5 to 2 m wide.

A total of 14 traps were used to sample the G-1 Channel: nine modified standard minnow traps and five large minnow traps. Fourteen stations were set up along the G-1 Channel, approximately 11 m apart, with one trap per station. This channel is approximately 153 m long and ranges from 5.5 to 3.2 m wide.

For both channels, the type of trap placed at each station was randomly determined before each sample. A total of five samples, or trap runs, were conducted at the George Channel and three samples were conducted at the G-1 Channel. Traps were baited with cat food, thrown into the center of the channel, and left fishing for approximately 2 h. Which trap was first removed from the water and in what order to continue pulling the traps was randomly determined for each trap run. Captured fish were measured in total length (mm), weighed (g), and, if previously unmarked, marked by clipping the pelvic fin. Due to low numbers of captures and almost no recaptures, a population estimate was not determined. Weights were compared to those recorded for

Lake Tuendae and Camp Cady. Temperature and dissolved oxygen data were also collected from both channels at the time of sampling.

CHAPTER 3

RESULTS

Lake Tuendae

April 2004

A total of 2,433 Mohave tui chub were captured during April 2004, with 732 recaptures. Excluding recaptures, fish captured had a mean total length (± SD) of 100 mm (± 25.92), ranging from 40 to 245 mm (n = 1697; Table 4). Fish weighed during this trapping period had a mean weight of 23.9 g (± 18.93), ranging from 0.6 to 73.2 g (n = 111; Table 5). Pupfish captured during this sample totaled 71, with a mean total length of 33 mm (± 4.2), while 42 mosquito fish captured had a mean total length of 37 mm (± 5.7).

April trap analyses. There were five different types of traps used in this trapping design. A Chi-square test showed a significant difference in captures among trap types ($p < 0.001$; $\chi^2 = 2959.1$; d.f. = 4; Figure 6). The large minnow traps captured more fish than would be expected if all trap types were equally effective. The standard minnow, extended minnow, square 2-hole and square 1-hole all captured fewer fish than expected.

Length-frequency histograms of total length (mm) for fish captured, excluding recaptures, were constructed for each trap type. The large minnow trap, excluding sample 4, captured 1,096 individuals with a size range of 75-245 mm and a modal size class of 100-109 mm (Figure 7). The distribution of new captures for the square

Table 4. Number of captures and total lengths (mm) of Mohave tui chub measured at Lake Tuendae, Camp Cady and China Lake. Means of lengths were calculated for individual fish, i.e., recaptures were excluded.

Trapping Location	Trapping Dates	Number of Total Fish Captured	Number of Recaptures	Total Length (mm)			
				n	Mean	SD	Range
Lake Tuendae	April 28-30 2004	2,433	736	1,697	100	25.92	40-245
	October 20-21 2004	4,553	1,685	2,868	97	20.40	41-279
	October 18-20 2005	4,872	1,979	2,893	92	20.54	41-320
Camp Cady	October 19 2004	176	—	176	110	17.33	65-170
China Lake	November 1-3 2004	183	3	180	109	34.97	37-176

Table 5. Weights (g) and total lengths (mm) of Mohave tui chub measured at Lake Tuendae, Camp Cady and China Lake.

Trapping Location	Trapping Dates	Total Fish Measured	Weight (g)			Total Length (mm)		
			Mean	SD	Range	Mean	SD	Range
Lake Tuendae	April 28-30 2004	111	23.9	18.93	1.1-73.2	114	37.5	43-179
	October 20-21 2004	143	23.9	27.94	2-150	111	37.22	48-232
Camp Cady	October 19 2004	175	17.1	9.29	4-64	110	17.34	65-170
China Lake	November 1-3 2004	147	26.1	15.44	1-84	123	21.21	77-176

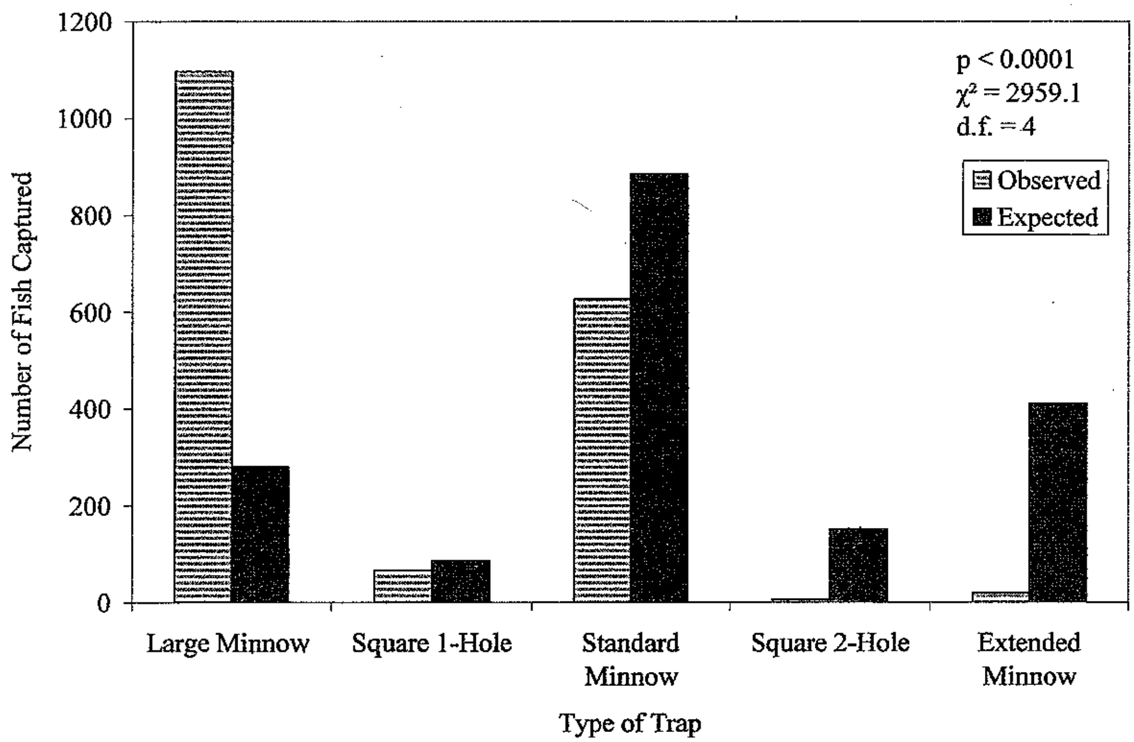

Figure 6. Frequency of captures of Mohave tui chub in different trap types for April 2004 in Lake Tuendae. Data from sample four were excluded because only large minnow traps were used. Total captures for each trap type was compared to the expected number of captures based on a proportion to account for the different numbers of each trap type.

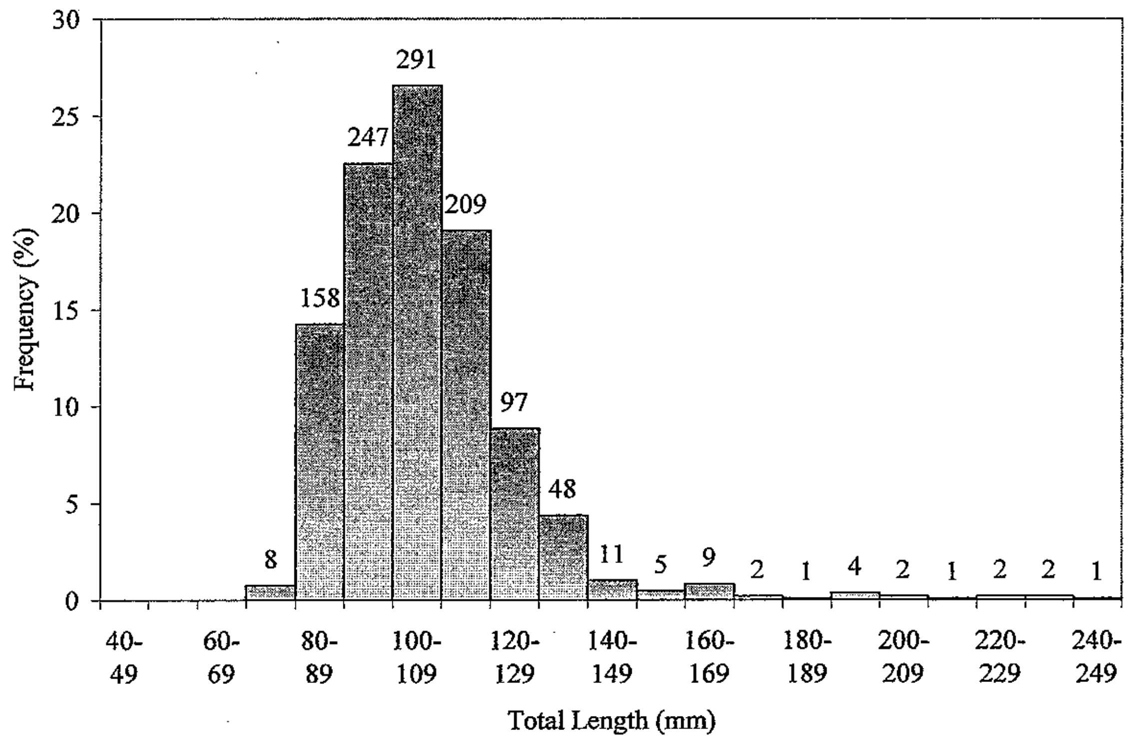

Figure 7. Length-frequency distribution of total length (mm) for all Mohave tui chub captured by the large minnow traps (n = 13) for April 2004 trapping period at Lake Tuendae, excluding pass four because only large minnow traps were used. Frequencies displayed are percent of total captures (n = 1,096), numbers at top of bars indicate number of individuals in that size class.

minnow trap with one opening ranged from 82 to 149 mm (n = 66) with a modal size class of 110-119 mm (Figure 8). The standard minnow trap captured a size range of 40-150 (n = 626) with a modal size class of 60-69 mm (Figure 9). While both the square minnow trap that opened at both ends and the extended minnow trap had a low number of captures, these ranged from 95-125 (n = 6) and 28-115 (n = 20), respectively. In comparing these histograms, the large minnow trap captured the largest size classes while the standard and extended minnow traps captured the smallest. The greatest range of size classes was captured by the large minnow and standard minnow traps.

The catch per unit effort (CPUE) for each trap type was calculated for the number of Mohave tui chub captured per trapping hour (Table 6). This analysis excluded sample four because only large minnow traps were deployed. The number of fish captured was divided by the amount of traps for each trap type to standardize the different amount of traps used. This was then divided by the total hours that trap type spent fishing. The large minnow trap had the highest CPUE, capturing 0.56 fish per trapping hour. The square minnow trap with one opening had the second highest CPUE of 0.53 fish per trapping hour. The standard minnow captured 0.04 fish per trapping hour, while the square minnow trap with two openings had a CPUE of 0.03. The extended minnow had the lowest CPUE, capturing 0.01 fish per trapping hour.

<u>October 2004</u>

For the October 2004 trapping period, the number of Mohave tui chub captured totaled 4,553, with 1,685 recaptures. Excluding recaptures, these fish had a mean total length of 97 mm (± 20.40), ranging from 41 to 279 mm (n = 2,868; Table 4). Fish

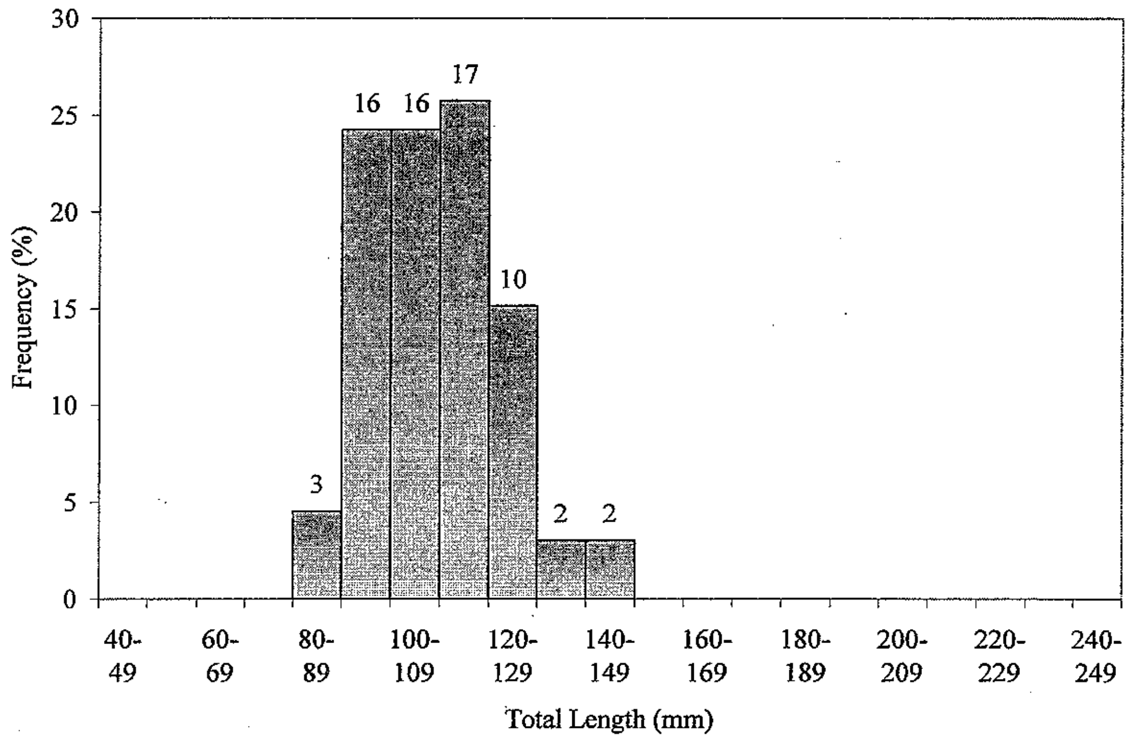

Figure 8. Length-frequency distribution of total length (mm) for all Mohave tui chub captured by the square minnow trap with one opening (n = 4) for April 2004 trapping period at Lake Tuendae. Frequencies displayed are percent of total captures (n = 66), numbers at top of bars indicate number of individuals in that size class.

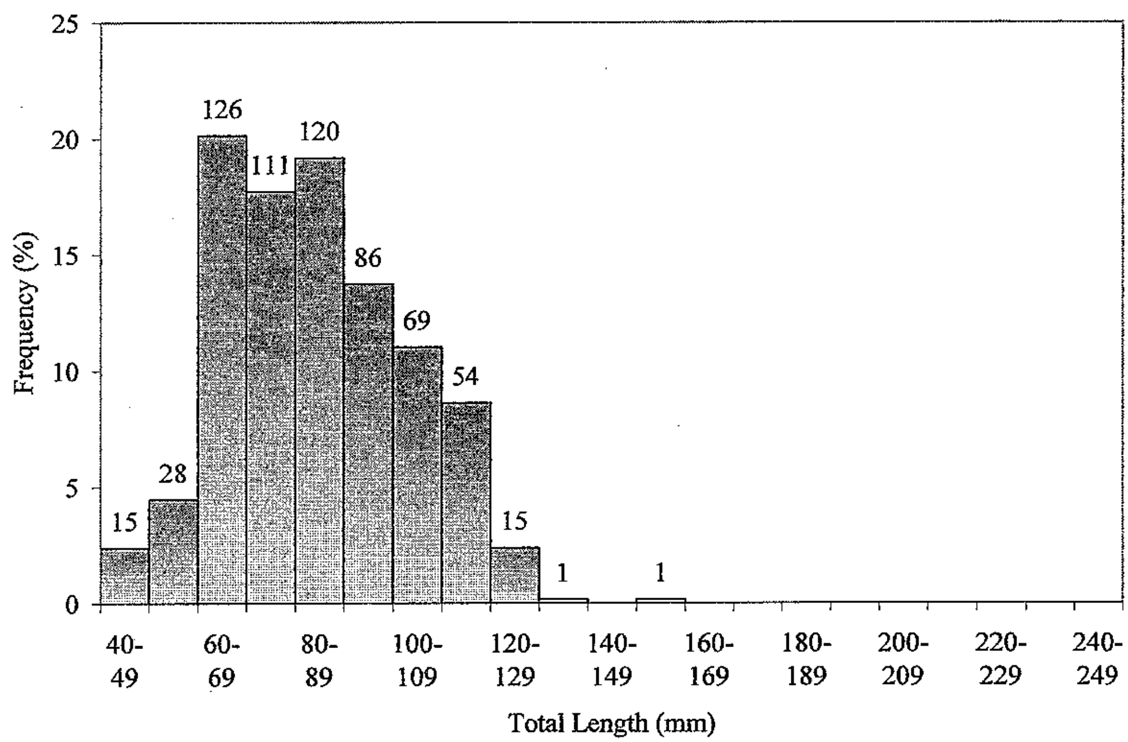

Figure 9. Length-frequency distribution of total length (mm) for all Mohave tui chub captured by the standard minnow trap (n = 41) for April 2004 trapping period at Lake Tuendae. Frequencies displayed are percent of total captures (n = 626), numbers at top of bars indicate number of individuals in that size class.

Table 6. Catch per unit effort for each trap-type for April 2004 trapping period, including all captures and excluding sample four because only large minnow traps were used. The mean size fish captured and standard deviation for each trap-type is also displayed.

Trap-Type	CPUE (# Fish/# Trap/Total Hours)	Total Fish Captured	Total Number of Traps	Total Hours Fishing (h:min)	Mean Total Length (mm)	Size Range	SD
Large Minnow	0.56	1096	13	151:27	106	75 - 245	19.27
Square 1-Hole	0.53	66	4	31:35	109	82 - 149	14.18
Standard Minnow	0.04	626	41	379:38	84	40 - 150	18.79
Square 2-Hole	0.03	6	7	29:07	115	95 - 125	16.18
Extended Minnow	0.01	20	19	79:44	73	28 - 115	22.89

weighed during this trapping period had a mean weight of 23.9 g (± 27.94), ranging from 2 to 150 g (n = 143; Table 5). One pupfish and 48 mosquito fish were incidentally captured during this collection period; these fishes were not measured.

October 2005

For the October 2005 trapping period, the number of Mohave tui chub captured totaled 4,872, with 1,979 recaptures. Excluding recaptures, these fish had a mean total length of 92 mm (± 20.54), ranging from 41 to 320 mm (n = 2,893; Table 4). Fish were not weighed during this trapping period. Seven pupfish and 121 mosquito fish were incidentally captured during this collection period, these fishes were not measured. Temperature, pH, and dissolved oxygen were recorded during the trapping period (Table 7).

October trap analyses. A chi-squared analysis was used to determine the evenness of capture success for the two types of traps used for each of the October 2004 and October 2005 trapping periods. The October 2004 showed a significant difference in the amount of captures between trap types ($p < 0.001$; $\chi^2 = 2512.6$; d.f. = 1; Figure 10). The number of captures between trap types also was significant for the October 2005 data ($p < 0.001$; $\chi^2 = 2373.2$; d.f. = 1; Figure 11). For both trapping periods, the large minnow trap captured more fish than expected, while the modified standard minnow trap captured fewer fish than expected.

Length-frequency distributions were compiled for each type of trap to display the length distribution captured. Frequencies displayed are percent of total captures per size class, excluding recaptures. The modified standard minnow trap captured a range of 41-

Table 7. Water quality readings from Lake Tuendae, October 2005 and China Lake, November 2004, trapping periods.

Site	Trapping Dates	Mean pH	Mean DO	Mean Temp (°C)	Number of Fish Captured
Lake Tuendae	October 18-20, 2005	9.38	7.30	18.95	4872
China Lake	November 1-3, 2004	7.95	8.12	8.76	163

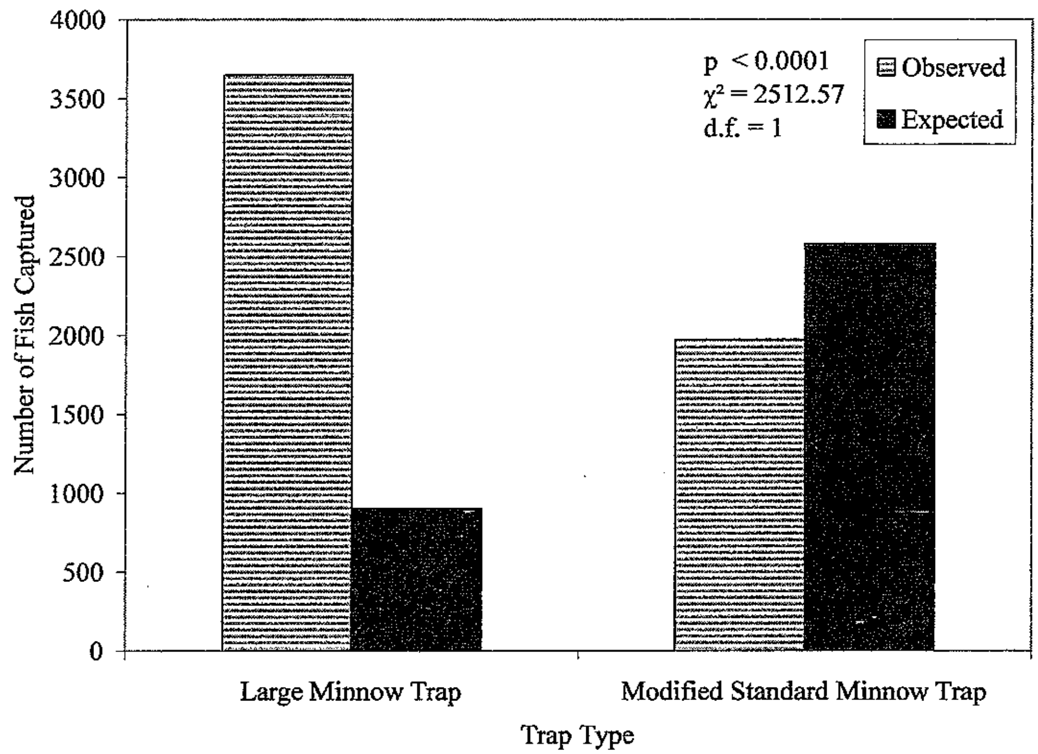

Figure 10. Frequency of captures of Mohave tui chub in different trap types in October 2004 in Lake Tuendae. Total captures for each trap type was compared to the expected number of captures based on a proportion to account for the different numbers of each trap type.

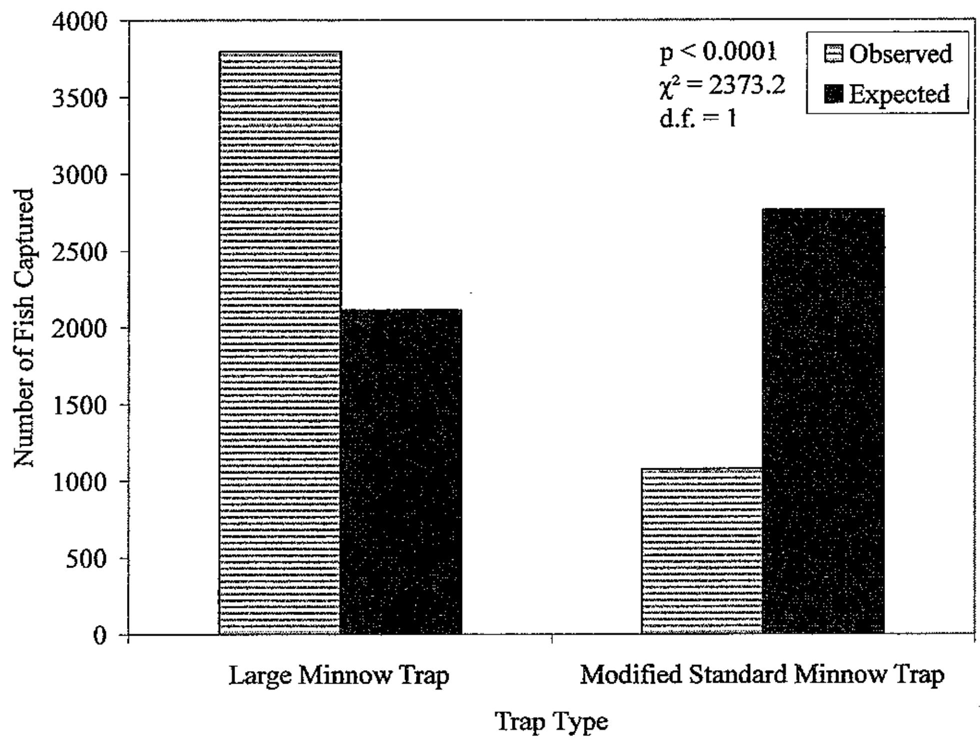

Figure 11. Frequency of captures of Mohave tui chub in different trap types in October 2005 in Lake Tuendae. Total captures for each trap type was compared to the expected number of captures based on a proportion to account for the different numbers of each trap type.

197 mm with a modal size of 80-89 mm (n = 710) for October 2004 (Figure 12) and a range of 41-185 with a modal size class of 70-79 mm for October 2005 (Figure 13). This trap captured a larger sized fish during both the October trappings than in the April. The largest sized fish captured in April by the standard minnow trap was 150 mm, while in October 2004 and October 2005 the largest sized fish captured was 197 and 185 mm, respectively. This could be a function of the size of the opening of the trap; in the October trappings this trap type was modified to have a larger opening.

The large minnow trap captured a range of 75-279 mm and a modal size class of 80-89 mm for October 2004 (Figure 14) and a range of 66-320 mm and a modal size of 80-89 mm for October 2005 (Figure 15). The modal size class captured by this trap type shifts from April 2004, of 100-109 mm, to 80-89 mm for both October 2004 and 2005 captures.

Camp Cady

The total number of *S. b. mohavensis* captured in October 2004 during the trapping effort totaled 176 fish. The mean total length was 110 mm (± 17.33), ranging from 65 mm to 170 mm (Table 4). These fish had a mean weight of 17.1 g (± 9.29) (Table 5).

China Lake Naval Air Weapons Station

The total number of *S. b. mohavensis* captured during this trapping effort totaled 183 fish with three recaptures. The mean total length, excluding recaptures, was 109 mm (± 34.97), ranging from 37 mm to 176 mm (Table 4). These fish had a mean weight

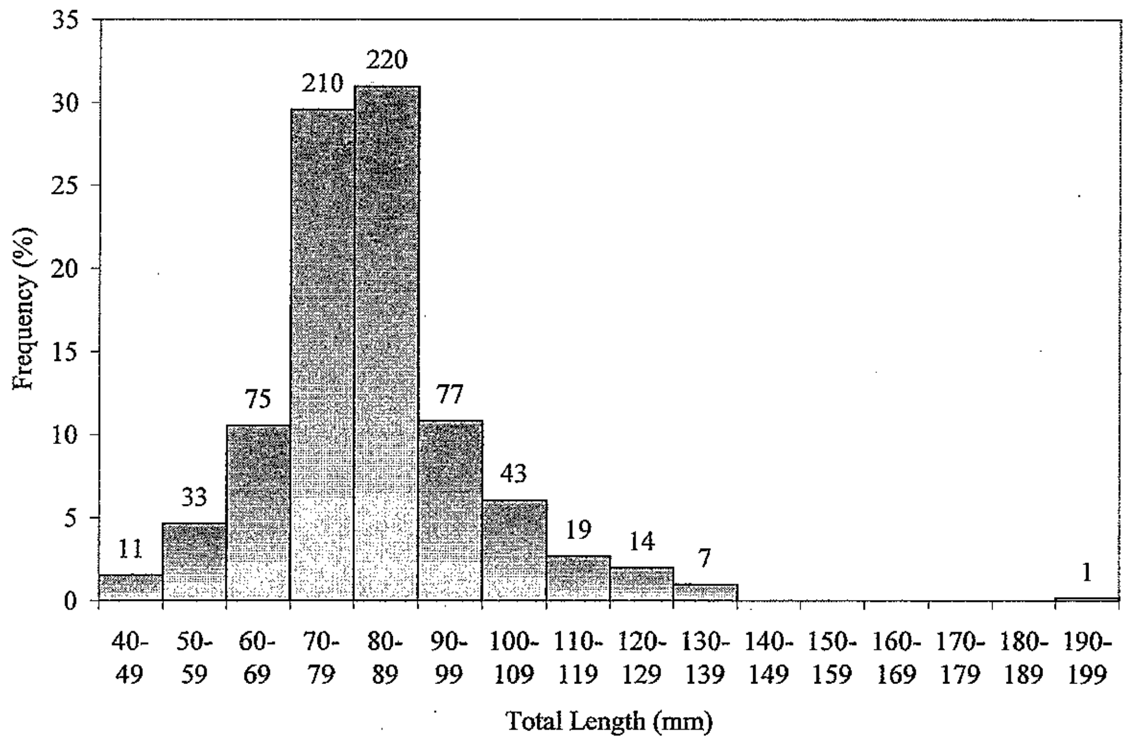

Figure 12. Length-frequency distribution of total length (mm) of individual Mohave tui chub, excluding recaptures, captured by modified standard minnow traps (n = 17) during the October 2004 trapping period in Lake Tuendae. Frequencies displayed are percent of total captures (n = 710), numbers at top of bars indicate number of individuals in that size class.

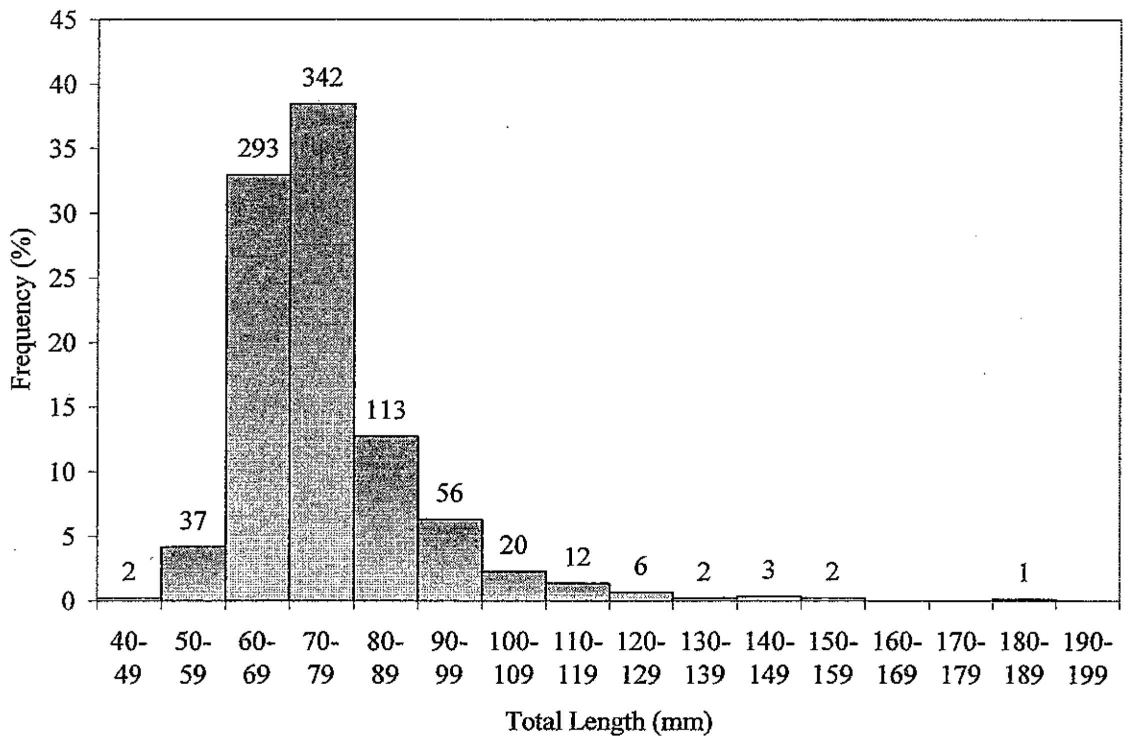

Figure 13. Length-frequency distribution of total length (mm) of individual Mohave tui chub, excluding recaptures, captured by modified standard minnow traps (n = 17) during the October 2005 trapping period in Lake Tuendae. Frequencies displayed are percent of total captures (n = 889), numbers at top of bars indicate number of individuals in that size class.

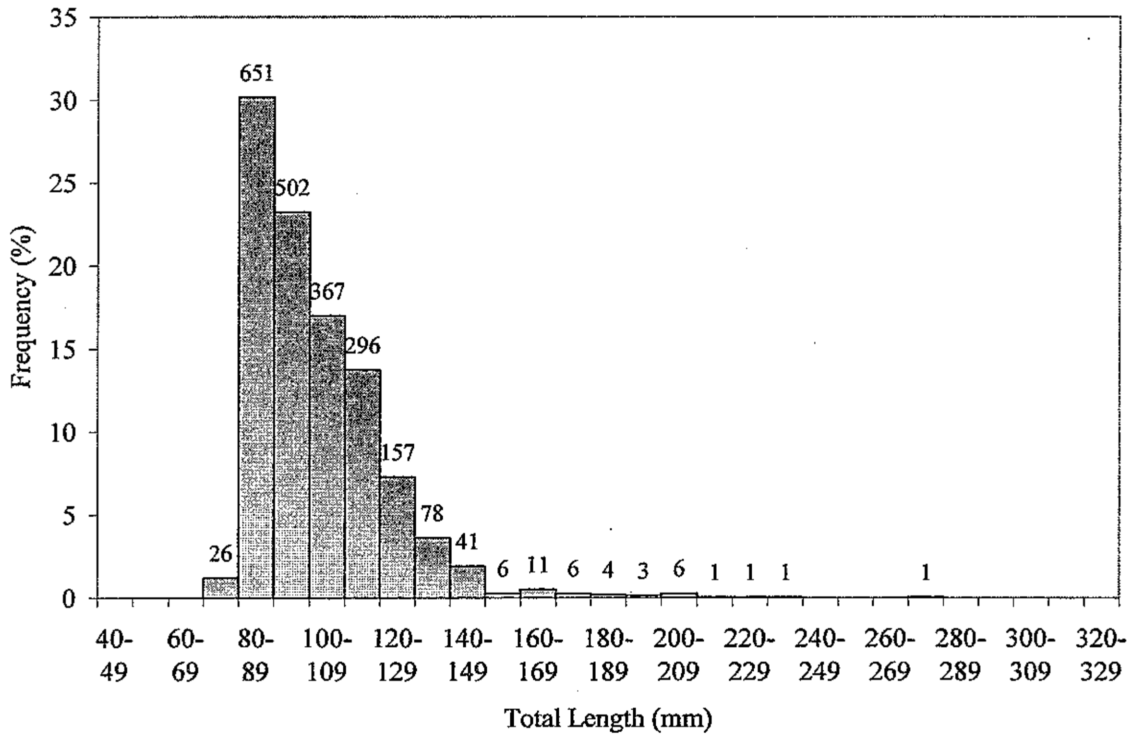

Figure 14. Length-frequency distribution of total length (mm) of individual Mohave tui chub, excluding recaptures, captured by large minnow traps (n = 13) during the October 2004 trapping period in Lake Tuendae. Frequencies displayed are percent of total captures (n = 2,158), numbers at top of bars indicate number of individuals in that size class.

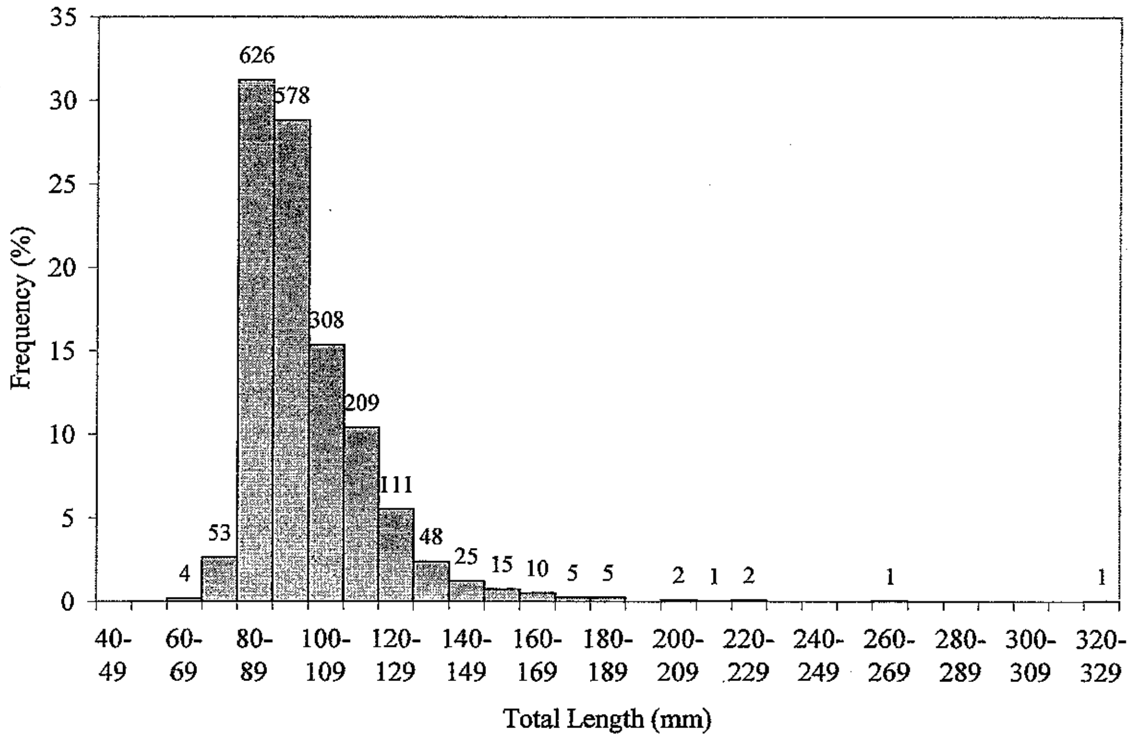

Figure 15. Length-frequency distribution of total length (mm) of individual Mohave tui chub, excluding recaptures, captured by large minnow traps (n = 13) during the October 2005 trapping period in Lake Tuendae. Frequencies displayed are percent of total captures (n = 2,004), numbers at top of bars indicate number of individuals in that size class.

of 17.1 g (± 15.44) (Table 5). Temperature, pH, and dissolved oxygen were recorded during the trapping period (Table 7).

Length-Weight Relationships

Length and weight data were collected during the April 2004 and October 2004 trapping periods at Lake Tuendae. Total length (mm) and weight (g) were correlated for April 2004 (Figure 16) and October 2004 (Figure 17). Total length (mm) and weight (g) were also correlated for data collected during the Camp Cady trappings (Figure 18) and China Lake trappings (Figure 19). These correlations show a similar length-weight curve between all sites.

Lengths and weights were further analyzed using a general linear regression comparing the $\log_{10}$ of total length and the $\log_{10}$ of the weight. Using the obtained slope parameters, the length-weight relationship constants *a* and *b* were calculated for each site. Mohave tui chub measured at Lake Tuendae in April 2004 had a length-weight relationship of $a = 0.0000167$ and $b = 2.93$ ($p < 0.001$; $R^2 = 0.95$; Figure 20). This analysis excluded those individuals which weighed over 200 g, because the balance did not exceed this weight, exact weights for these individuals were not determined. Data collected at Lake Tuendae during October 2004, had length-weight relationship of $a = 0.0000155$ and $b = 2.96$ ($p < 0.001$; $R^2 = 0.95$; Figure 21). The length-weight relationship for Mohave tui chub at Camp Cady was $a = 0.0000344$ and $b = 2.7714$ ($p < 0.001$; $R^2 = 0.88$; Figure 22). While China Lake measurements had a relationship of $a = 0.0000003$ and $b = 3.73$ ($p < 0.001$; $R^2 = 0.82$; Figure 23).

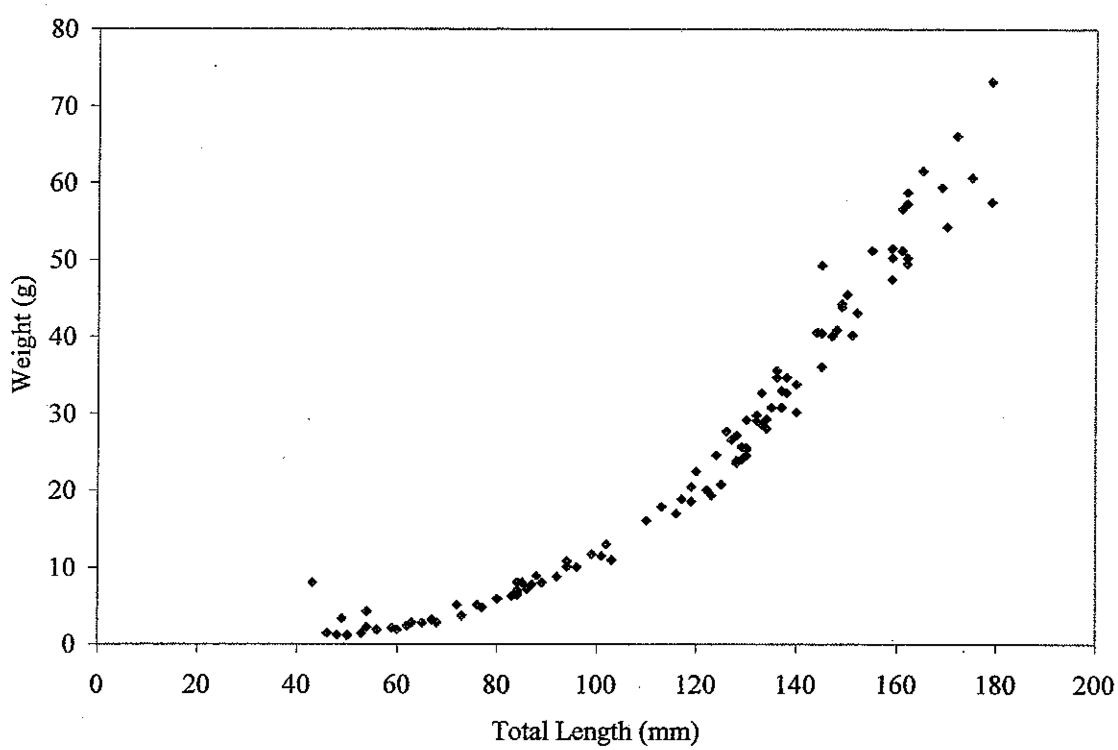

Figure 16. Total length (mm) and weight (g) for Mohave tui chub for data collected during April 2004 at Lake Tuendae (n = 111).

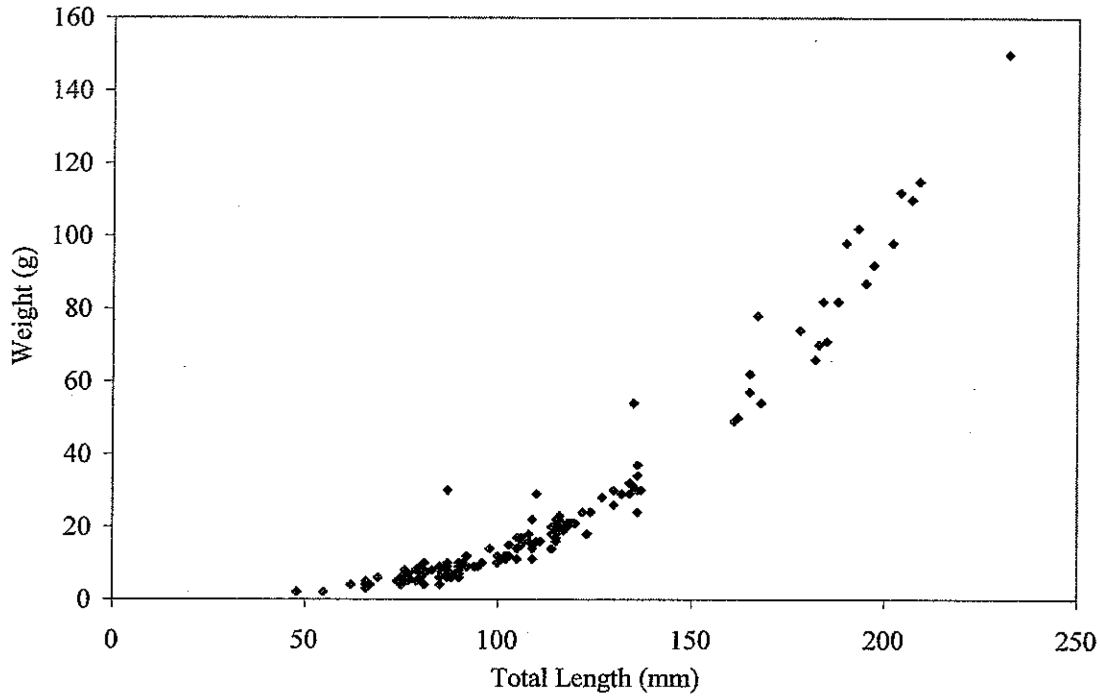

Figure 17. Total length (mm) and weight (g) for Mohave tui chub for data collected during October 2004 at Lake Tuendae (n = 143).

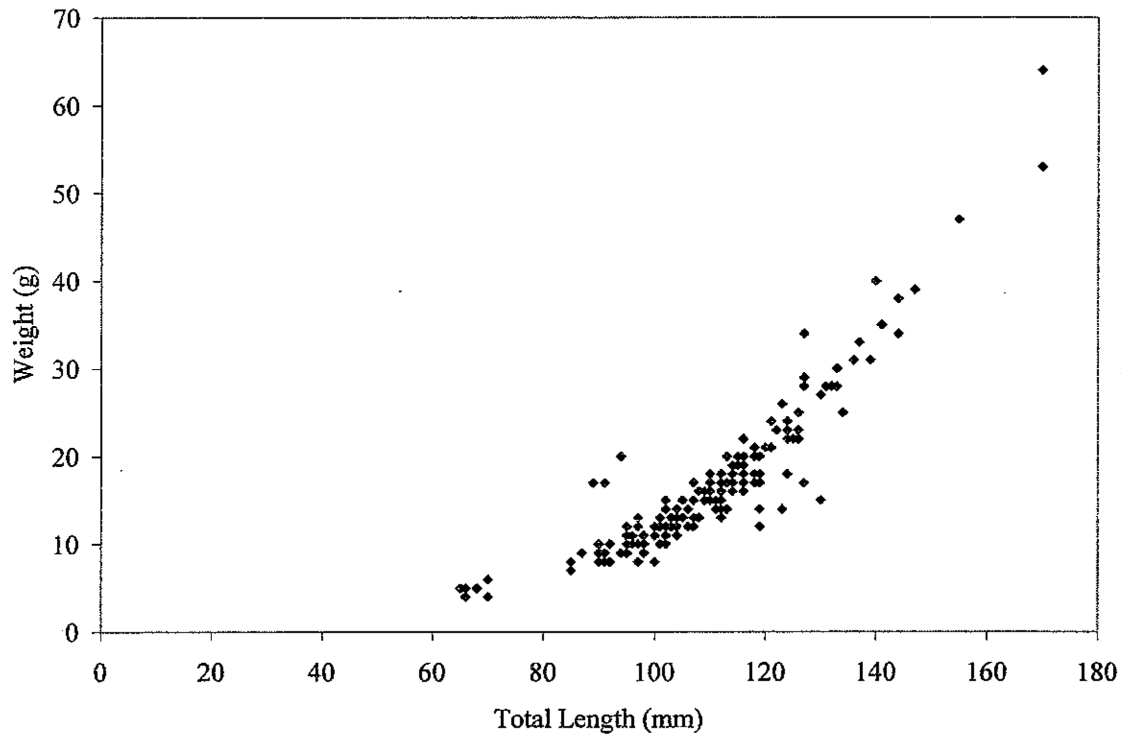

Figure 18. Total length (mm) and weight (g) for Mohave tui chub for data collected at Camp Cady, 2004 (n = 176).

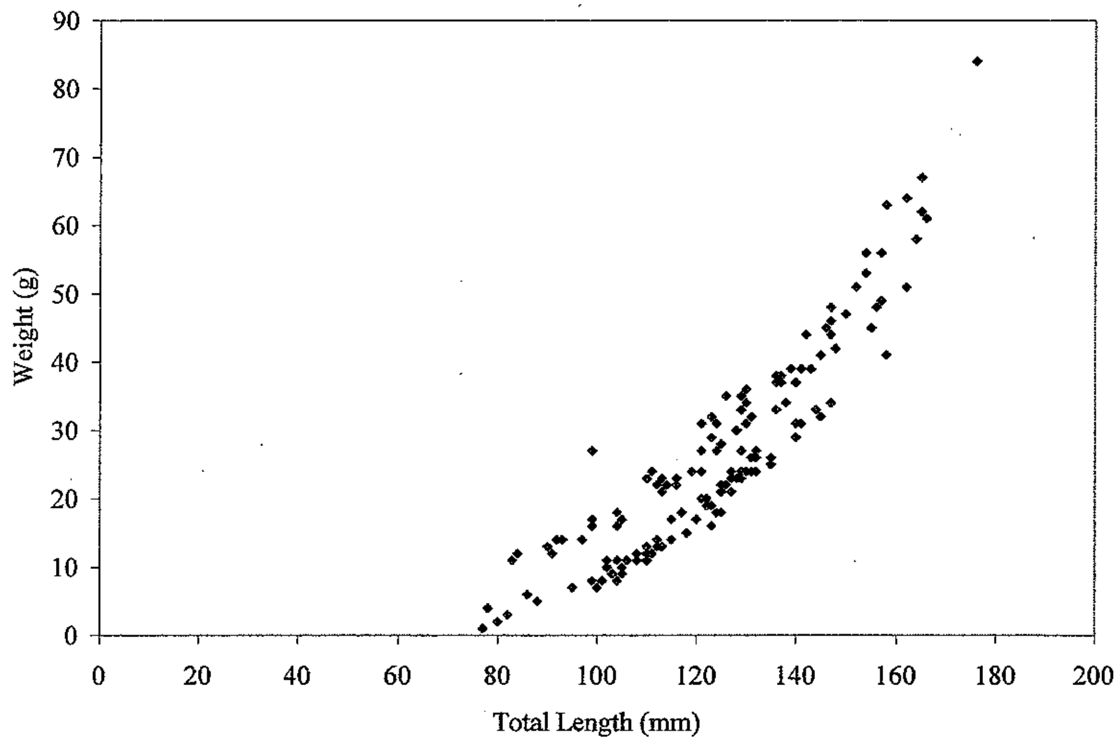

Figure 19. Total length (mm) and weight (g) for Mohave tui chub for data from China Lake 2004 (n = 180).

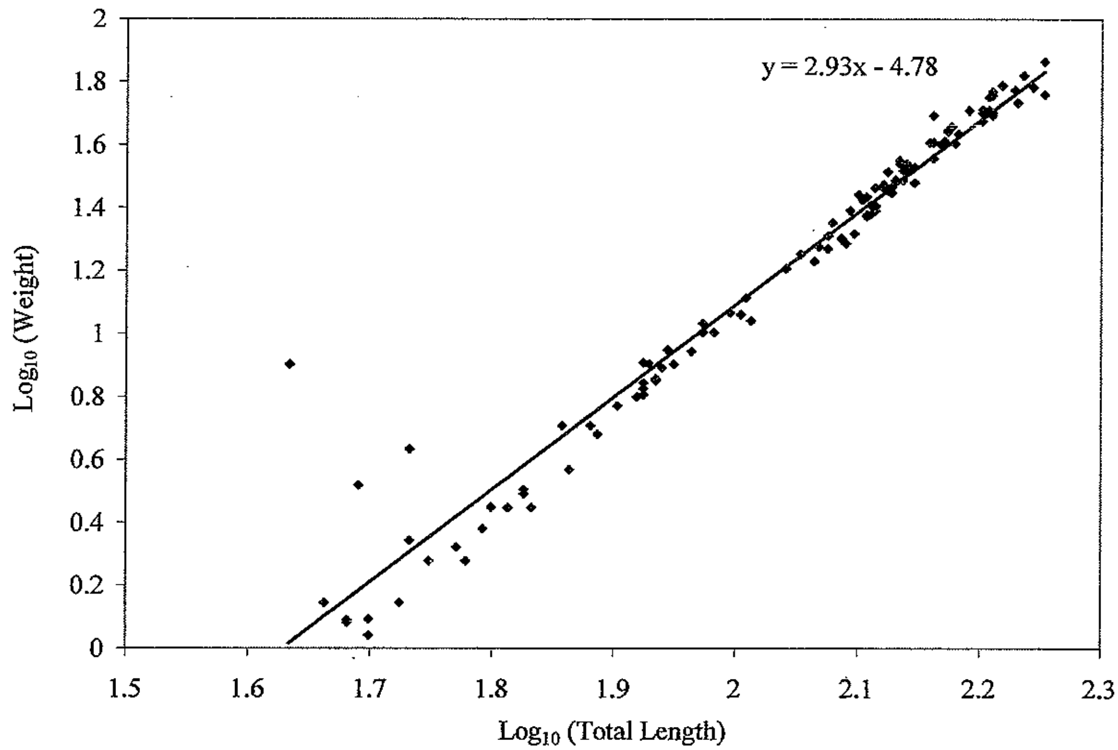

Figure 20. Length-weight relationship for Mohave tui chub for data collected during April 2004 at Lake Tuendae. A general regression analysis compared the $\log_{10}$ of weight and the $\log_{10}$ of total length ($a = 0.0000167$ and $b = 2.93$; $p < 0.001$; $R^2 = 0.95$).

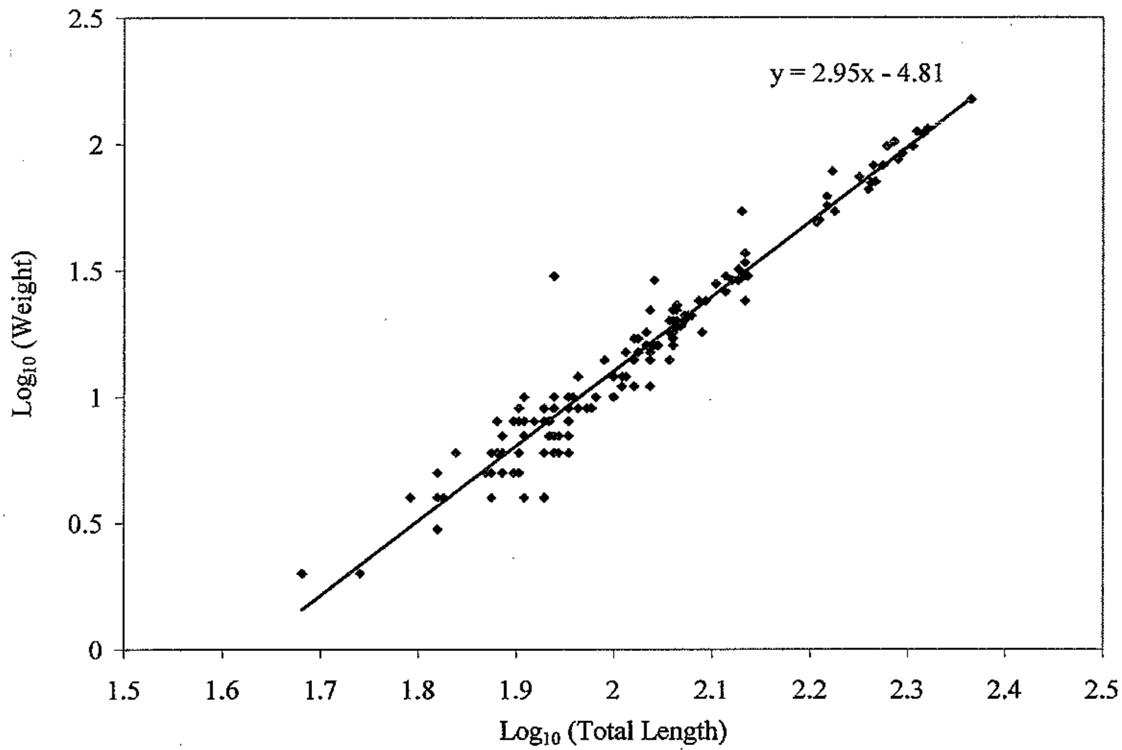

Figure 21. Length-weight relationship for Mohave tui chub for data collected during October 2004 at Lake Tuendae. A general regression analysis compared the $\log_{10}$ of weight and the $\log_{10}$ of total length ($a = 0.0000155$ and $b = 2.95$; $p < 0.001$; $R^2 = 0.95$).

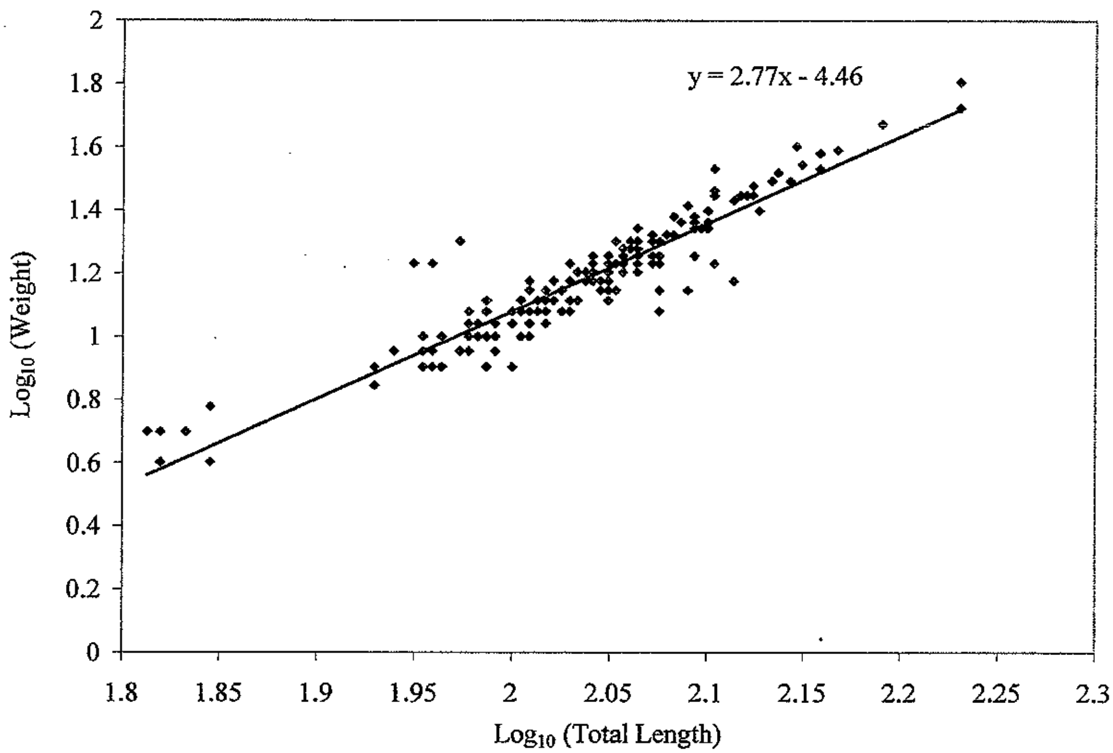

Figure 22. The length-weight relationship was determined for Camp Cady data collected in October 2004 using a general regression analysis of the $\log_{10}$ of weight and the $\log_{10}$ of total length ($a = 0.0000344$ and $b = 2.77$ $p < 0.001$; $R^2 = 0.88$).

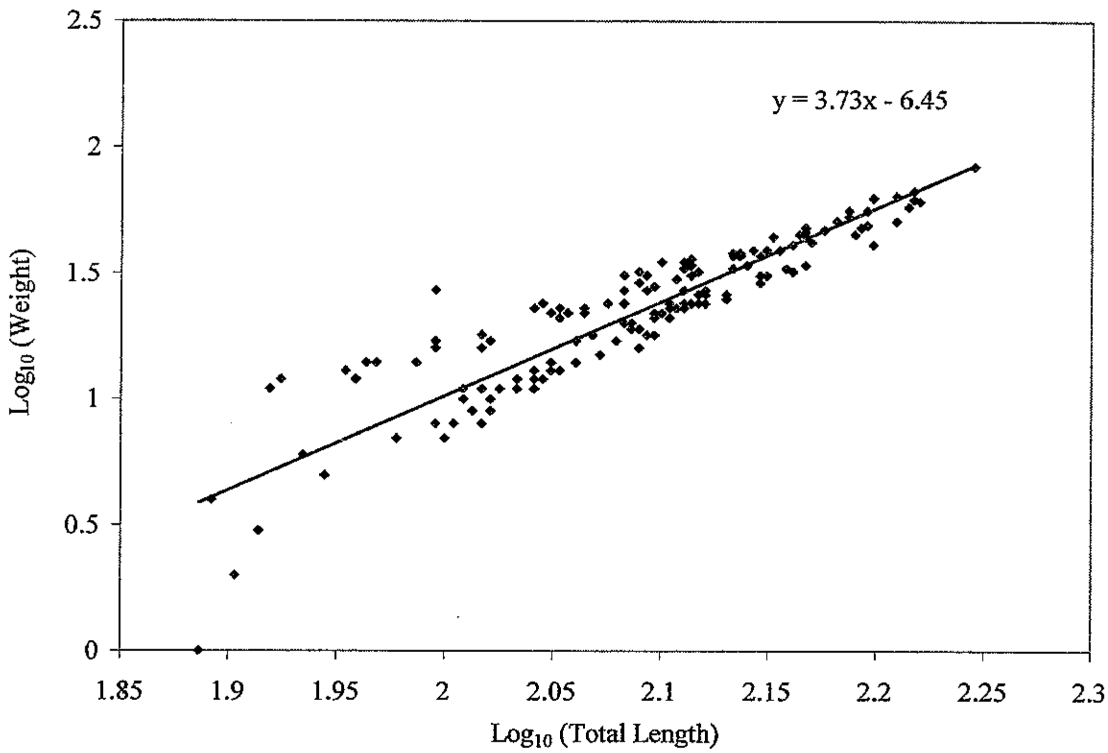

Figure 23. The length-weight relationship was determined for China Lake for data collected in November 2004 using a general regression analysis of the $\log_{10}$ of weight and the $\log_{10}$ of total length ($a = 0.0000003$ and $b = 3.73$; $p < 0.001$; $R^2 = 0.82$).

These relationships were compared between sites using an analysis of covariance (ANCOVA). The length and weight relationships, when comparing sampling times, were found to be significantly different ($P < 0.001$; $F = 19.43$; d.f. = 575; Figure 24). This indicates the length-weight relationships obtained for Lake Tuendae in April 2004 and October 2004, Camp Cady and China Lake were each significantly different from each other.

Length-frequency Distributions

The length distribution for Mohave tui chub, measured in total length (mm), were compiled for each trapping period. Frequencies were based on a percent of total captures for that size class, excluding recaptures. The Lake Tuendae, April 2004 trapping period captured a modal size of 100-109 mm and a range of 40-245 mm (n = 1,697) (Figure 25). To compare length distributions for all Lake Tuendae trapping periods, a length frequency distribution was compiled from the April data using only the standard minnow and large minnow traps (Figure 26). These traps were consistent for all trapping periods. The distribution of fish captured in April 2004 by standard minnow and large minnow traps maintains the same modal size class of 100-109 mm and a range of 40-245 mm (n = 1,617).

The length distribution for October 2004 (Figure 27) has a modal size class of 80-89 mm, with a range of 41-279 mm (n = 2,868). In comparison, the April modal size of 110-119 mm changes to 80-89 mm in October 2004. The length distribution for October 2005 (Figure 28) has the same modal size class of October 2004. Smaller size classes, though, increased from the October 2004 to the October 2005 distributions. For

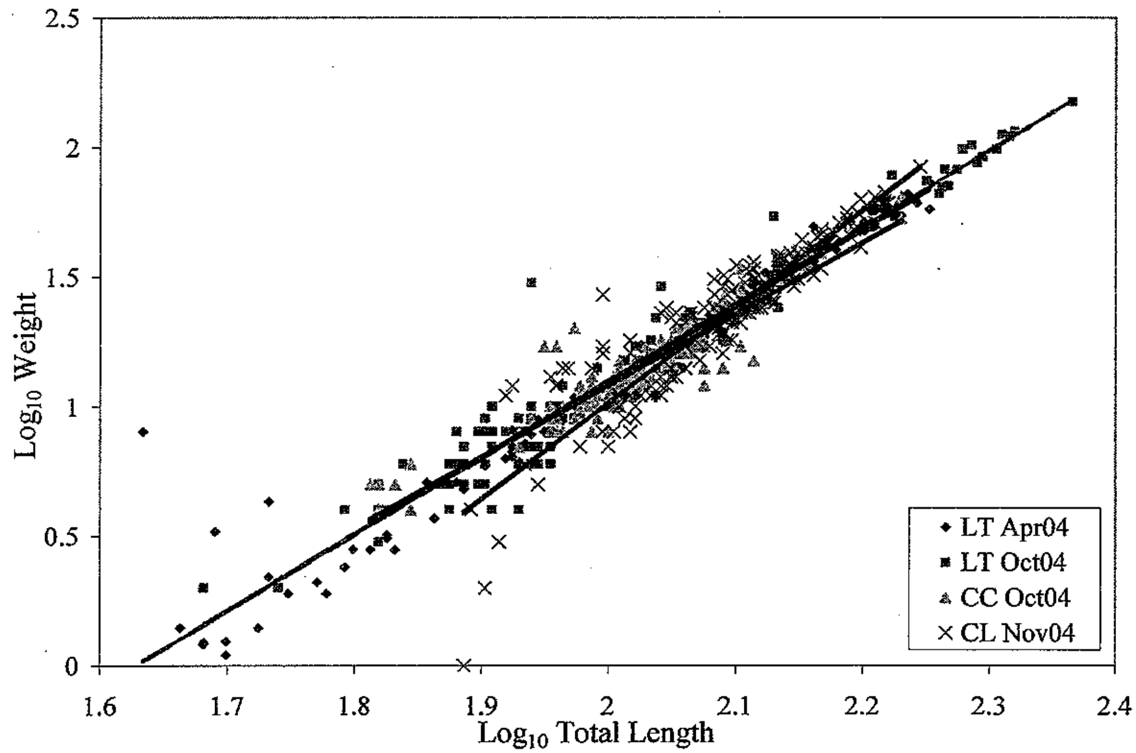

Figure 24. The length-weight relationships for all trapping periods at all sites, comparing the $\log_{10}$ of the length and the $\log_{10}$ of the weight. These relationships were found to be significantly different from each other using an ANCOVA ($P < 0.001$; $F = 19.43$; d.f. = 575).

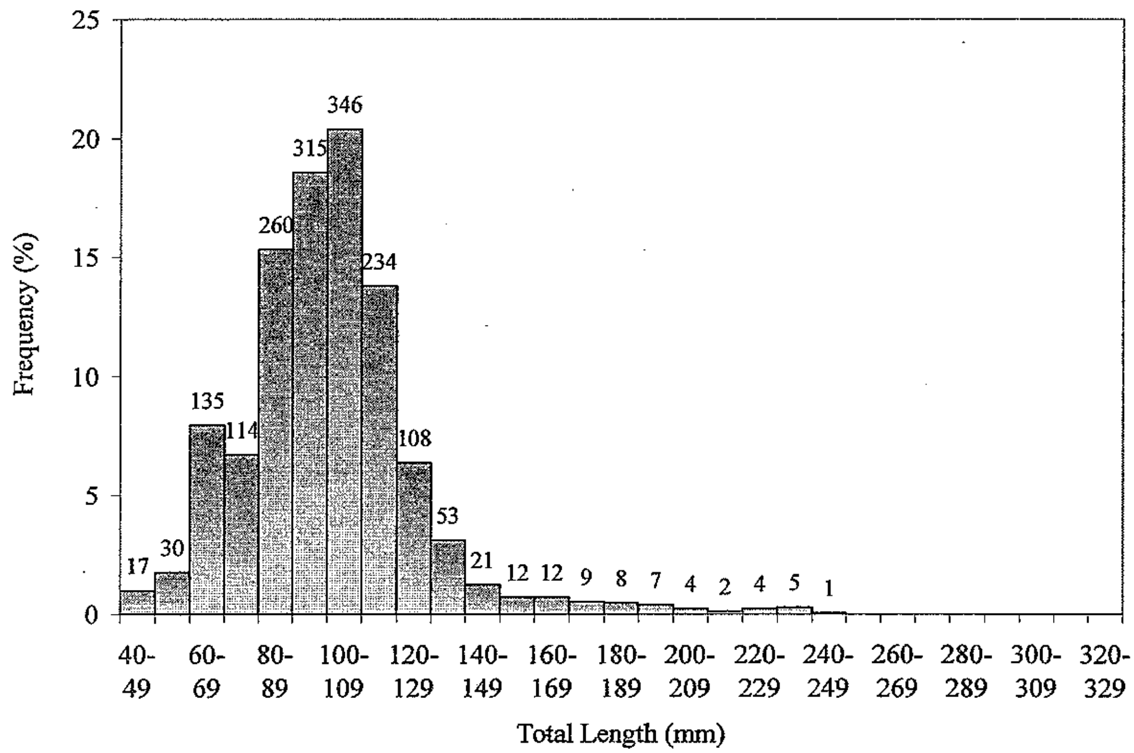

Figure 25. Length-frequency distribution of total length (mm) of individual Mohave tui chub, excluding recaptures, captured by all traps (n = 84) during the April 2004 trapping period in Lake Tuendae. Frequencies displayed are percent of total captures (n = 1,697), numbers at top of bars represent the number of individuals in that size class.

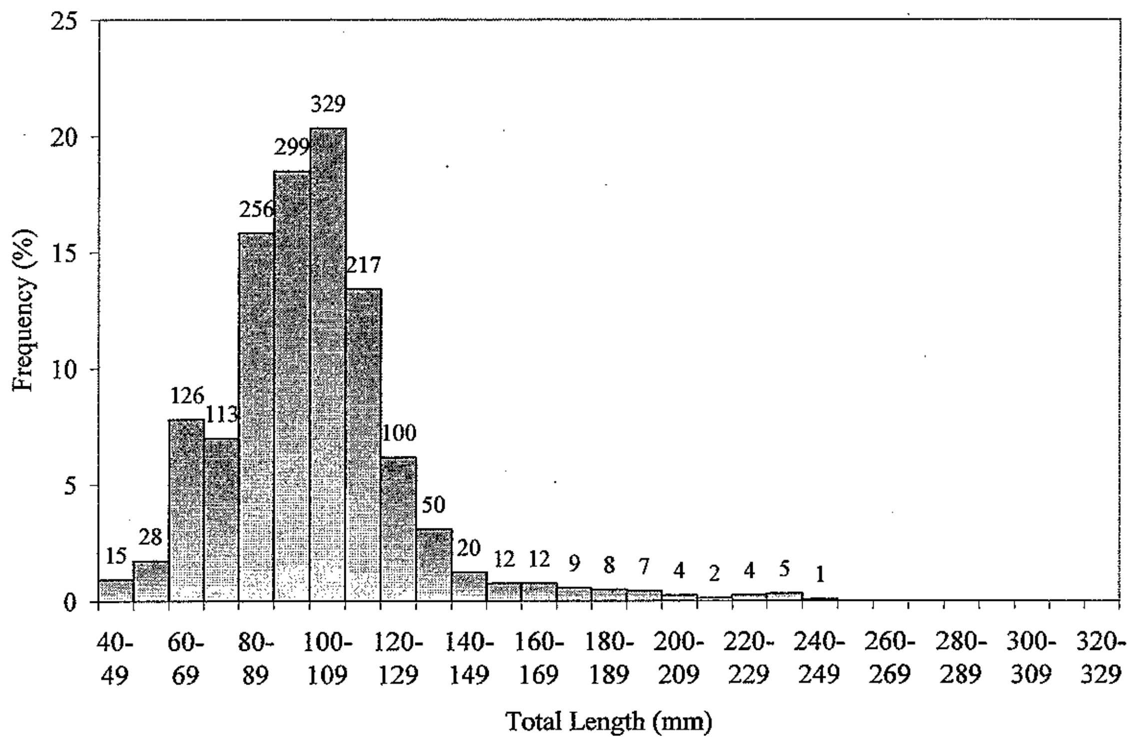

Figure 26. Length-frequency distribution of total length (mm) of individual Mohave tui chub, excluding recaptures, captured by standard minnow and large minnow traps (n = 54) during the April 2004 trapping period in Lake Tuendae. Frequencies displayed are percent of total captures (n = 1,617) for these traps, numbers at top of bars indicate number of individuals in that size class.

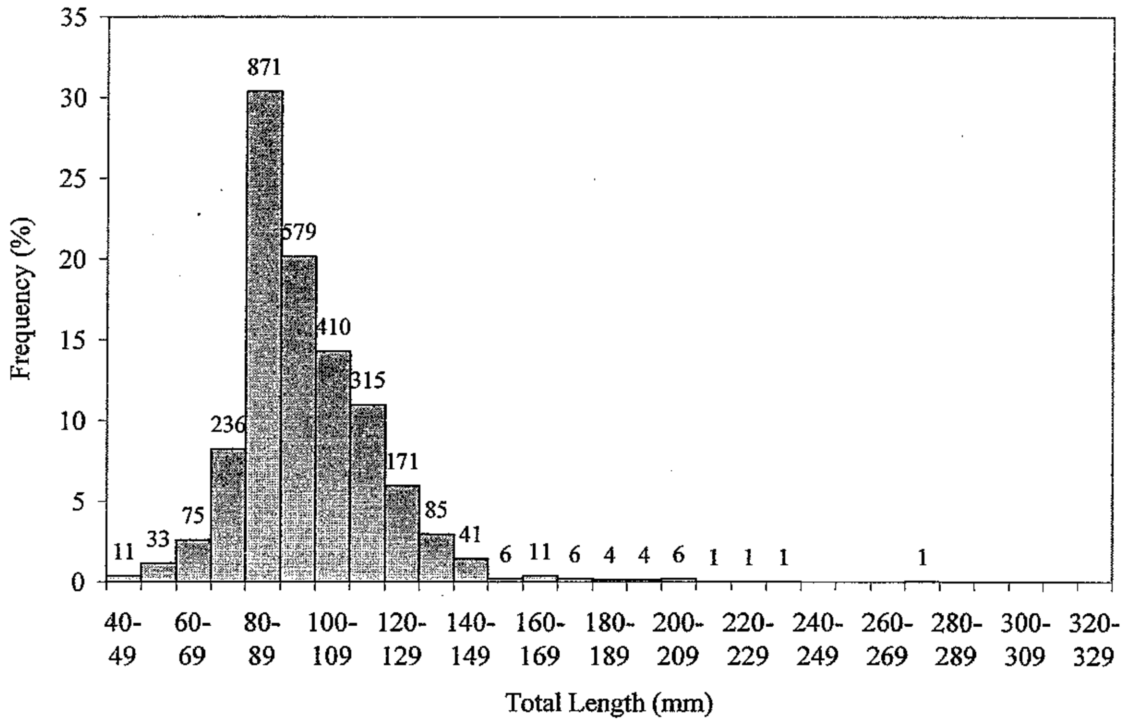

Figure 27. Length-frequency distribution of total length (mm) of Mohave tui chub, excluding recaptures, captured by all traps used during the October 2004 trapping period in Lake Tuendae, i.e., standard minnow and large minnow traps (n = 30). Frequencies displayed are percent of total captures (n = 2,868), numbers at top of bars represent the number of individuals in that size class.

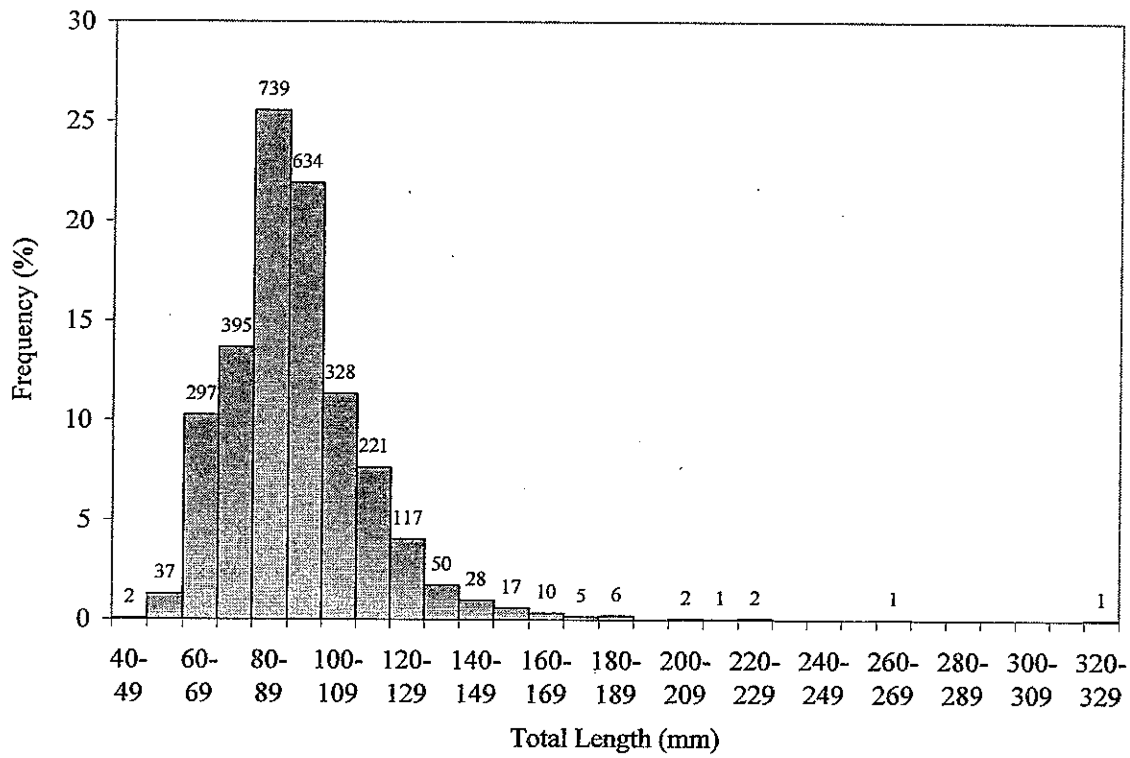

Figure 28. Length-frequency distribution of total length (mm) of individual Mohave tui chub, excluding recaptures, captured by all traps used during the October 2005 trapping period in Lake Tuendae, i.e., standard minnow and large minnow traps (n = 30). Frequencies displayed are percent of total captures (n = 2,893), numbers at top of bars represent the number of individuals in that size class.

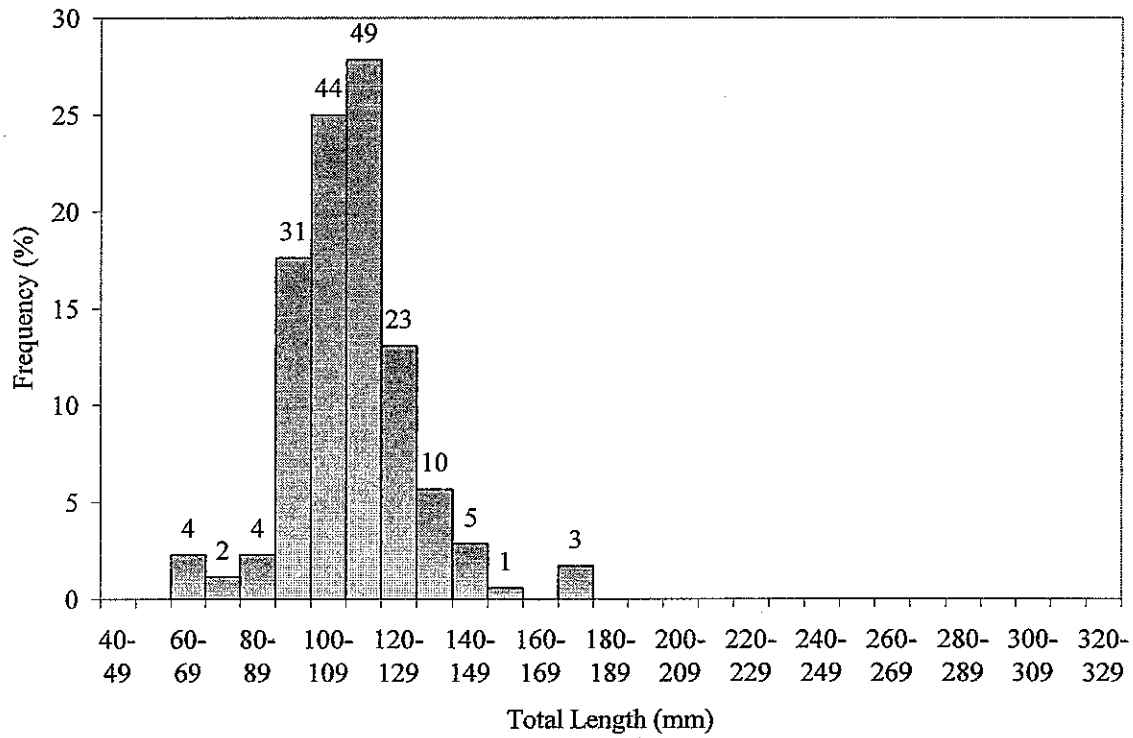

Figure 29. Length-frequency distribution for Mohave tui chub measured in total length (mm) during trapping in the West Pond at Camp Cady on October 19,2004. Frequencies are percent of total capture (n = 176), and numbers at the top of the bars indicate number of individuals in that size class.

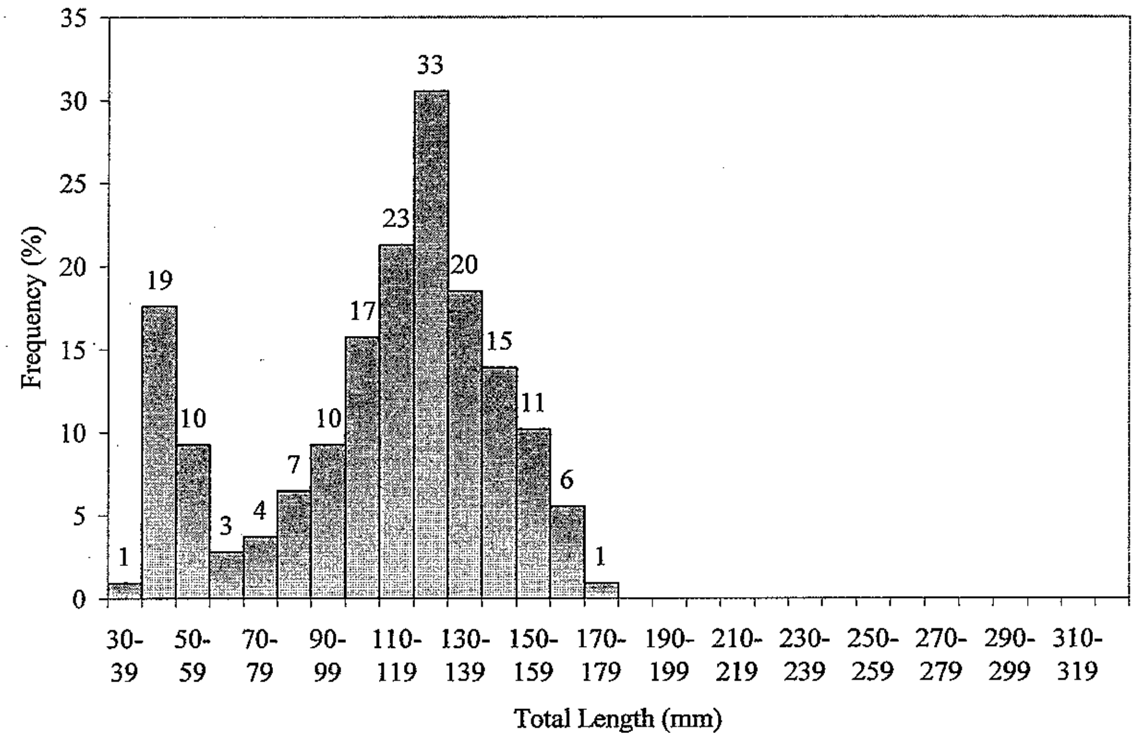

Figure 30. Length-frequency distribution for Mohave tui chub measured in total length (mm), excluding recaptures, at China Lake 2004. Frequencies are displayed as percent of total captures (n = 180), numbers at the top of the bars indicate the number of individuals in that size class.

example, the 60-69 mm size class increased by 7.6 % and 70-79 mm size class increased by 5.4 %. Camp Cady length distributions are displayed in a length-frequency histogram (Figure 29). This shows a modal class size of 110-119 mm and a range of 65-170. Total length frequency was also calculated for data collected at China Lake (Figure 30). This shows a modal class size of 120-129 mm and a range of 37-176 mm. Overall, Lake Tuendae data shows a broader distribution than China Lake, which in turn, has a broader distribution than Camp Cady, although Lake Tuendae also has a larger sample size.

Catch Curves

During this study I measured total length and standard length of Mohave tui chub that were collected by Vicker (1973) at Lake Tuendae. A general linear regression analysis was used to determine the relationship between standard length and total length ($y = 1.1408x + 5.668$; Figure 31). Standard length age classes, determined by Vicker (1973) using scale annuli, were converted to total length using this relationship. These size at age classes were than directly compared to total length data collected during this study period (Table 8). Due to overlap of lengths at specific ages, these lengths were assigned to a mixed age category. Taylor and McGriff (1985) also determined size at age classes for Mohave tui chub using scale annuli, these data were also converted to total length (Table 8). These age classes were not fit to current data due to the fact that exact length ranges were not reported.

A catch curve was determined for data collected by Vicker (1973) (Figure 32) and for data collected by Taylor and McGriff (1985) (Figure 32). The natural log of the

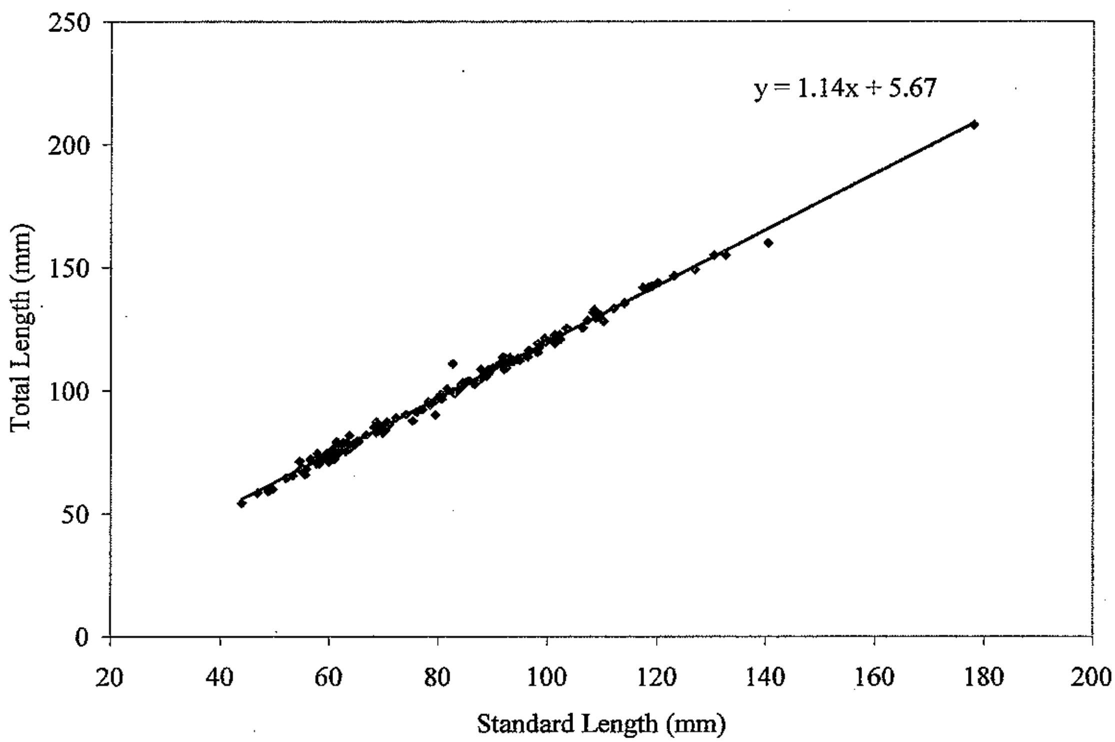

Figure 31. Relationship between standard length and total length of Mohave tui chub, collected by Vicker (1973) at Lake Tuendae, was determined using a general linear regression analysis ($y = 1.14x + 5.67$; $R^2 = 0.99$).

Table 8. Size at age classes for Mohave tui chub from Lake Tuendae, determined by Vicker (1973) and Taylor and McGriff (1985) converted to total length.

Data	Age Class	Standard Length (mm)	Estimated Total Length (mm)
Vicker (1973)	0+	27 - 42	35 - 53
	1+	54 - 85	66 - 102
	2+	76 - 121	92 - 143
	3+	116 - 138	138 - 162
	4+	161 - 215	189 - 250
		Mean Standard Length (mm)	Mean Total Length (mm)
Taylor and McGriff (1985)	0+	48	60
	1+	64	79
	2+	82	99
	3+	104	124
	4+	110	131

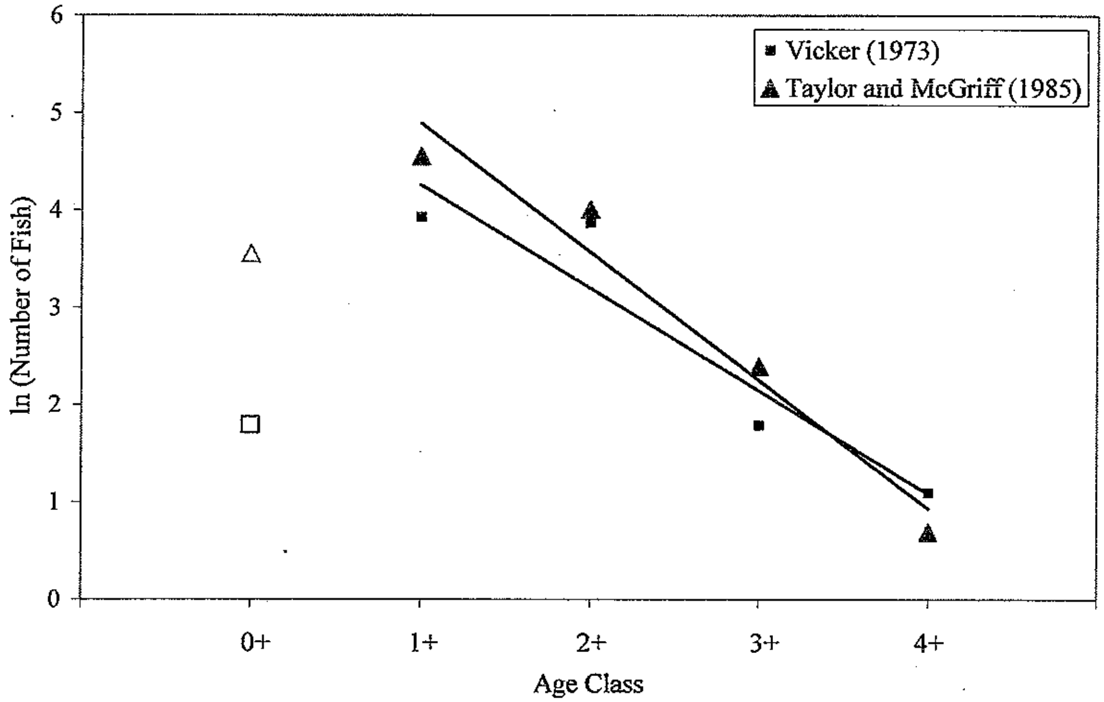

Figure 32. Catch curve for Mohave tui chub, data collected by Vicker (1973) and Taylor and McGriff (1985) at Lake Tuendae. The curve displays the natural log of the number of fish captured per age class; the slope of the right limb estimates the annual survival rate, i.e., from one age class to the next. Data collected by Vicker (1973) ($y = -1.06x + 6.38$) estimates a higher survival rate ($\hat{S} = 0.35$) than using data collected by Taylor and McGriff (1985) ($y = -1.32x + 7.53$; $\hat{S} = 0.27$).

amount of fish captured in a specific age class was compared to that specific age class. Adult annual survival rate was then estimated from the slope of the descending right limb of the curve. Annual survival rate from Vicker (1973) was calculated to be 0.35 fish/yr to survive from one age class to the next, while data from Taylor and McGriff (1985) resulted in a survival rate of 0.27. According to these analyses, Mohave tui chub had a higher annual survival rate in 1973 than in 1984; however, it is not clear whether this difference reflects actual difference in annual survival or differences in aging criteria.

These estimates were also calculated for data collected during this study at Lake Tuendae. For April 2004, using only standard minnow and large minnow trap captures for comparisons, the annual survival rate was estimated at 0.56 (Figure 33). The catch curve for data collected in October 2004 estimated a survival rate of 0.43 (Figure 34). Data collected in October 2005 data estimated a survival rate of 0.40 (Figure 35). According to these analyses, survival rate is higher in April than October. Current estimates are higher than those estimates obtained from Vicker (1973) and Taylor and McGriff (1985) data.

Population Estimates

To test if the assumptions of the Schnabel method were met for generating the population estimates for Lake Tuendae, the proportion of recaptures over total captures in sample *t* (R_t/C_t) was plotted against the number of previously marked individuals (M_t) for each estimate. For April 2004, R_t/C_t plotted against M_t resulted in a linear relationship ($R^2 = 0.88$; Figure 36). The linearity of R_t/C_t compared to M_t increased for both the October 2004 test of assumptions ($R^2 = 0.98$; Figure 36) and the October 2005 test of

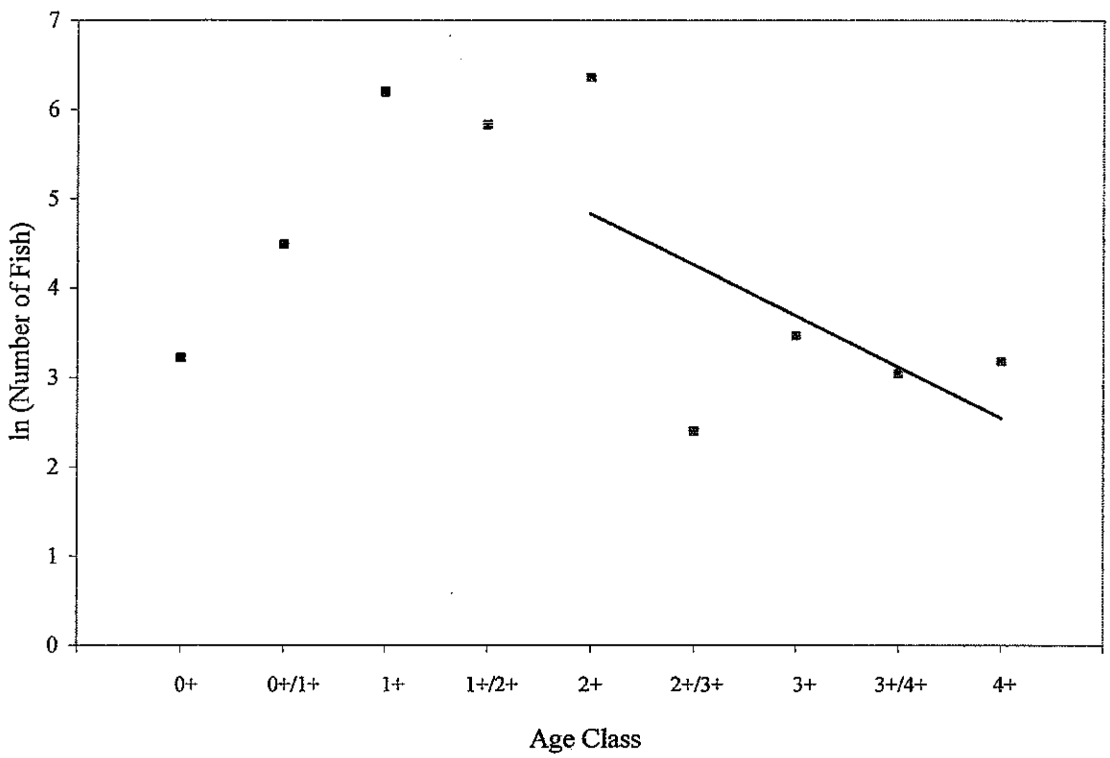

Figure 33. Catch curve for Mohave tui chub captured by the standard minnow and large minnow traps, excluding recaptures, during the April 2004 trapping period at Lake Tuendae. The curve displays the natural log of the number of fish captured per age class; the slope of the right limb estimates the annual survival rate, i.e., from one age class to the next ($\hat{S} = 0.56$; $y = -0.57x + 7.69$; $R^2 = 0.34$). Age classes were determined from age-length relationships from Vicker (1973).

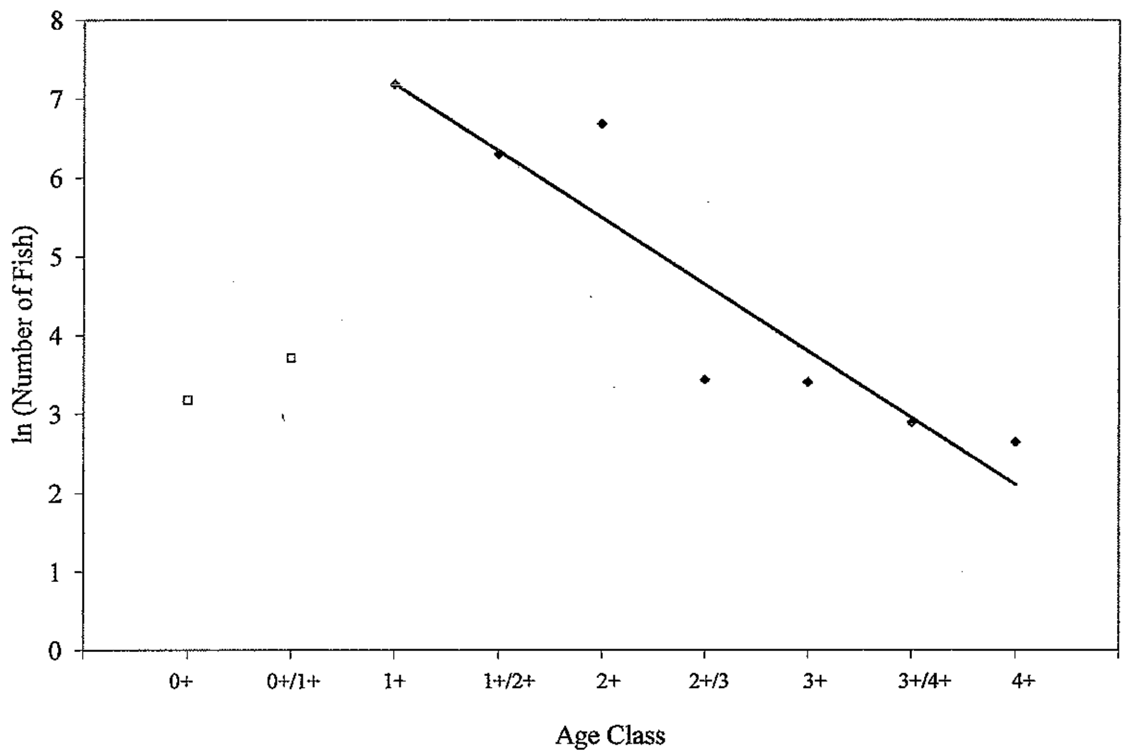

Figure 34. Catch curve for Mohave tui chub captured, excluding recaptures, by all traps during the October 2004 trapping period, i.e., standard minnow and large minnow traps. The curve displays the natural log to the number of fish captured per age class; the slope of the descending right limb estimates the rate of survival from one age class to the next ($\hat{S} = 0.42$; $y = -0.85x + 9.73$; $R^2 = 0.86$). Age classes were determined from age-length relationships from Vicker (1973).

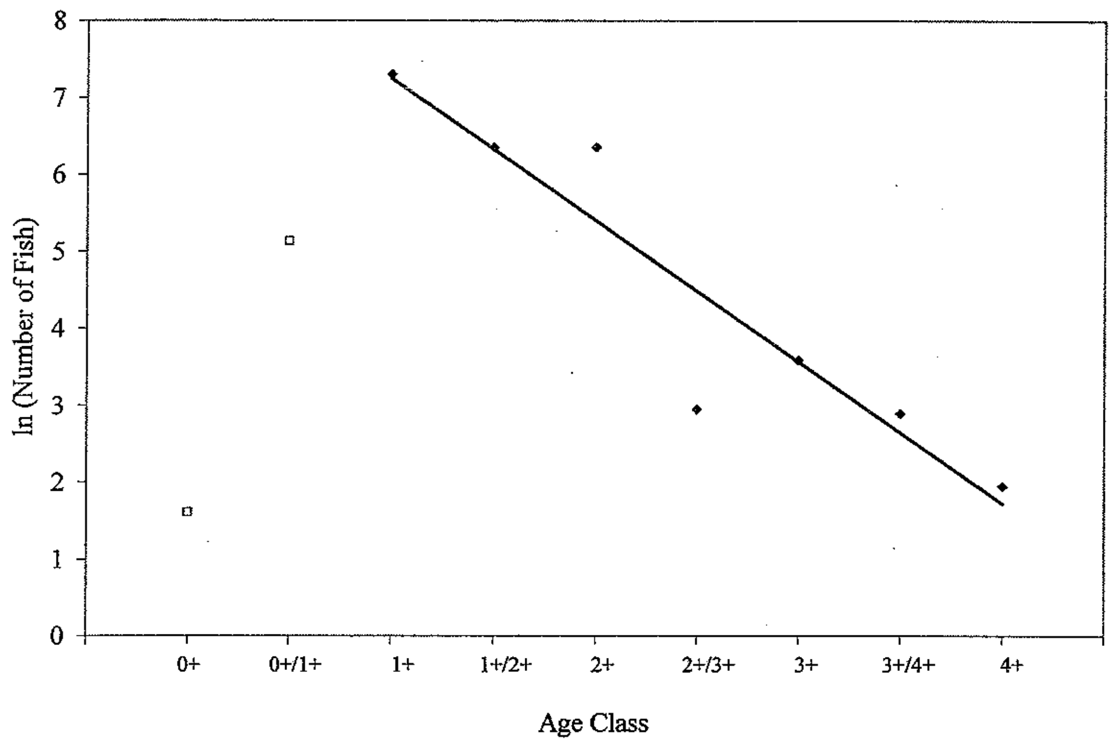

Figure 35. Catch curve for Mohave tui chub captured, excluding recaptures, by all traps during the October 2005 trapping period, i.e., standard minnow and large minnow traps. The curve displays the natural log to the number of fish captured per age class; the slope of the descending right limb estimates the rate of survival from one age class to the next ($\hat{S} = 0.40$; $y = -0.92x + 10.0$; $R^2 = 0.88$). Age classes were determined from age-length relationships from Vicker (1973).

assumptions ($R^2 = 0.98$; Figure 36). The linearity of these relationships indicates the assumptions of the Schnabel method were met for all population estimates. (Krebs, 1989).

Population estimates were determined for each trapping period using the Schnabel method. The population estimate for Mohave tui chub at Lake Tuendae in April 2004 was 2,241 fish (95% C.I.: 2,090-2,416; Figure 37). For October 2004, the population estimate was 3,708 (95% C.I.: 3,539-3,894; Figure 37) and was 3,355 for October 2005 (95% C.I.: 3,214-3,510; Figure 37). Judging by the 95% CI, population size had increased from the April 2004 to October 2004 and then decreased in October 2005. However, the upper confidence limit for October 2004 is very close to the lower limit in October 2005.

Habitat Use

For both the October 2004 and 2005 trapping designs at Lake Tuendae, the location of the traps with respect to shore was randomly determined. Traps were placed either at the bank of the lake, a quarter distance into the lake (approximately 10 m from the bank), or in the middle of the lake. A Chi-square analysis was used to test if fish were equally captured among these locations in the lake. This analysis excluded captures from trapping stations at the corners of the lake to account for an edge effect; stations excluded were 1, 2, 14-17, 29, and 30.

During the October 2004 trapping period, the bank location captured fewer fish than would be expected if the number of captures were evenly distributed between trap locations. Conversely, the quarter and middle locations captured more fish than expected

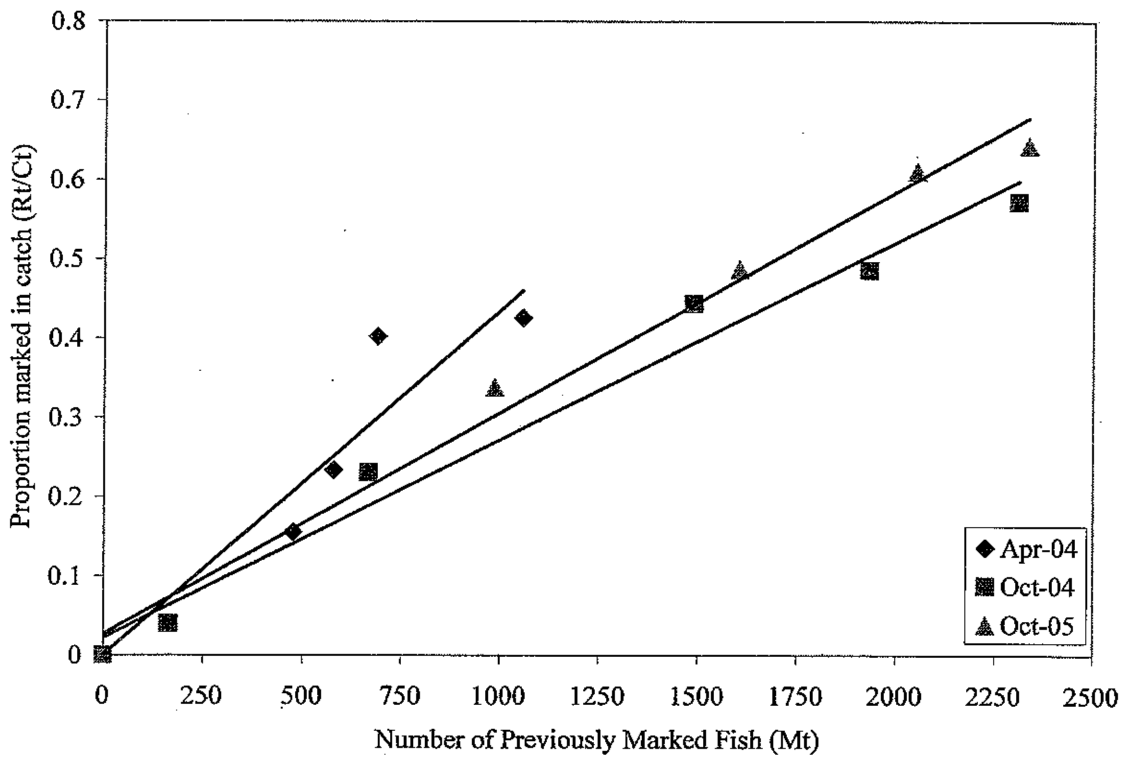

Figure 36. Graphical determination to evaluate if all assumptions of the Schnabel method were adequately met for population estimates for Mohave tui chub at Lake Tuendae. Proportion of recaptures over total captures in sample *t* (R_tC_t) to the number of previously marked individuals (M_t) will be linear if all assumptions are met. Linearity of data from April 2004 ($R^2 = 0.88$), October 2004 ($R^2 = 0.98$), and October 2005 ($R^2 = 0.98$) determines the assumptions were met for these estimates.

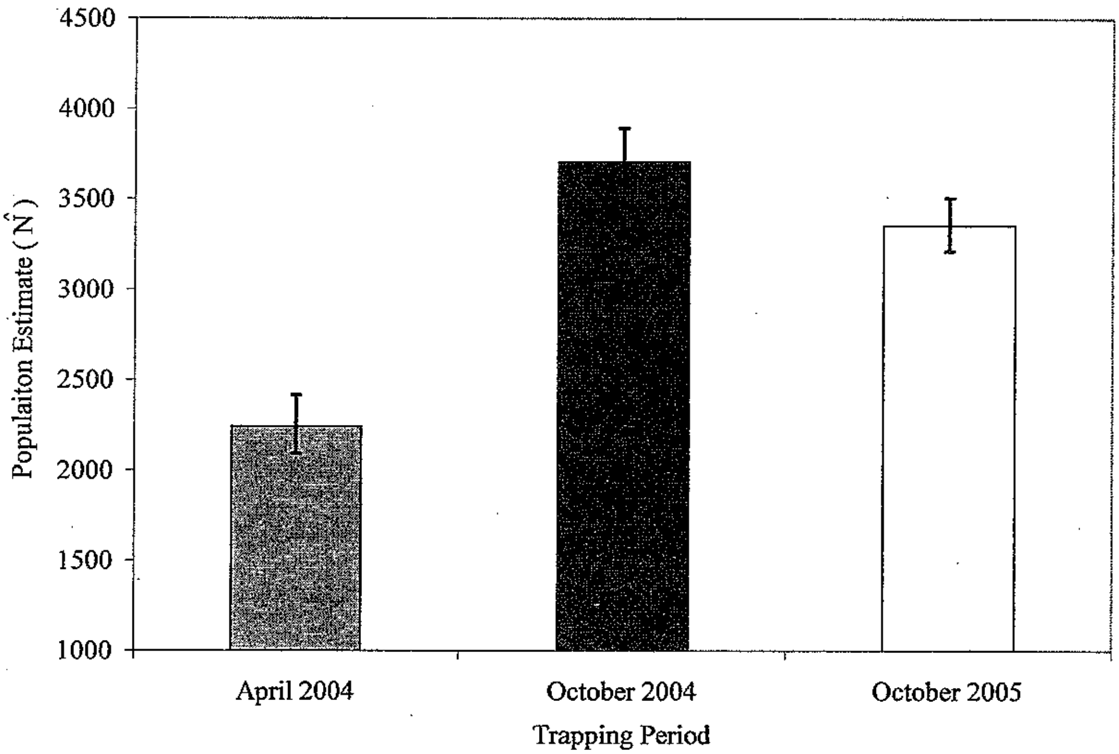

Figure 37. Population estimates based upon Schnabel estimation procedure for Mohave tui chub at Lake Tuendae from April 2004, October 2004, and October 2005 trapping periods ($\hat{N} \pm 95\%$ CI).

($p < 0.001$; $\chi^2 = 112.7$; d.f. = 2; Figure 38). The October 2005 trappings captured fewer fish than expected at the bank and quarter distance locations, while the middle captured more than expected ($p < 0.001$; $\chi^2 = 29.8$; d.f. = 2; Figure 39). During both the October 2004 and 2005 trapping periods the bank location captured fewer fish and the middle location captured more fish than would be expected.

During collections efforts, some traps were left fishing longer than others due to different processing times at trap stations. An ANCOVA was used to test if the number of fish captured was influenced by the time traps were operational at each trap location. For both the October 2004 ($P = 0.71$; $F = 0.14$; d.f. = 127; Figure 40) and the October 2005 ($P = 0.30$; $F = 1.07$; d.f. = 120; Figure 41) data, the number of fish captured did not significantly increase with the amount of time traps were in the water at the different trap locations.

Further analyzing the difference in total captures at trap locations, the mean total length of fish captured at these locations was compared using a one way analysis of variance (ANOVA). For the October 2004 trapping period, the mean total length captured between trap locations was significantly different ($P < 0.001$; $F = 40.05$; d.f. = 2; Figure 42). While the quarter and middle distance location captures did not significantly differ from each other, they were significantly different compared to the mean total length of captures at the bank location. The October 2005 trappings also significantly differed in mean total length between locations ($P < 0.001$; $F = 13.66$; d.f. = 2; Figure 43). While the quarter location lengths did not differ significantly from the bank and middle locations, the bank and middle locations significantly differed from each other.

Comparing these differences in fish size at location of capture, during both trapping periods, traps at the bank locations captured a smaller sized fish, while those at the middle locations captured a larger sized fish.

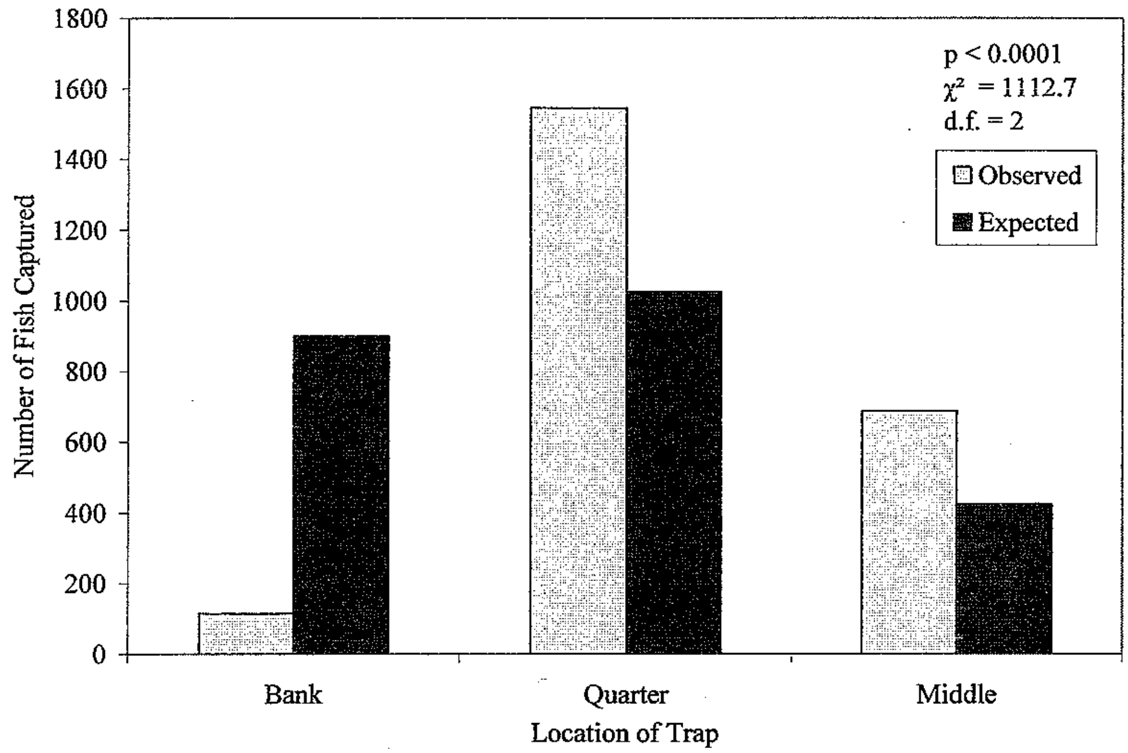

Figure 38. Number of Mohave tui chub captured at each trapping location within the lake during the October 2004 trapping period at Lake Tuendae. The number of captures per trap location, based on a proportion to account for the different amount of traps, was statistically compared to the number of captures that would be expected if fish were captured evenly within the lake, using a Chi-square test ($p < 0.001$).

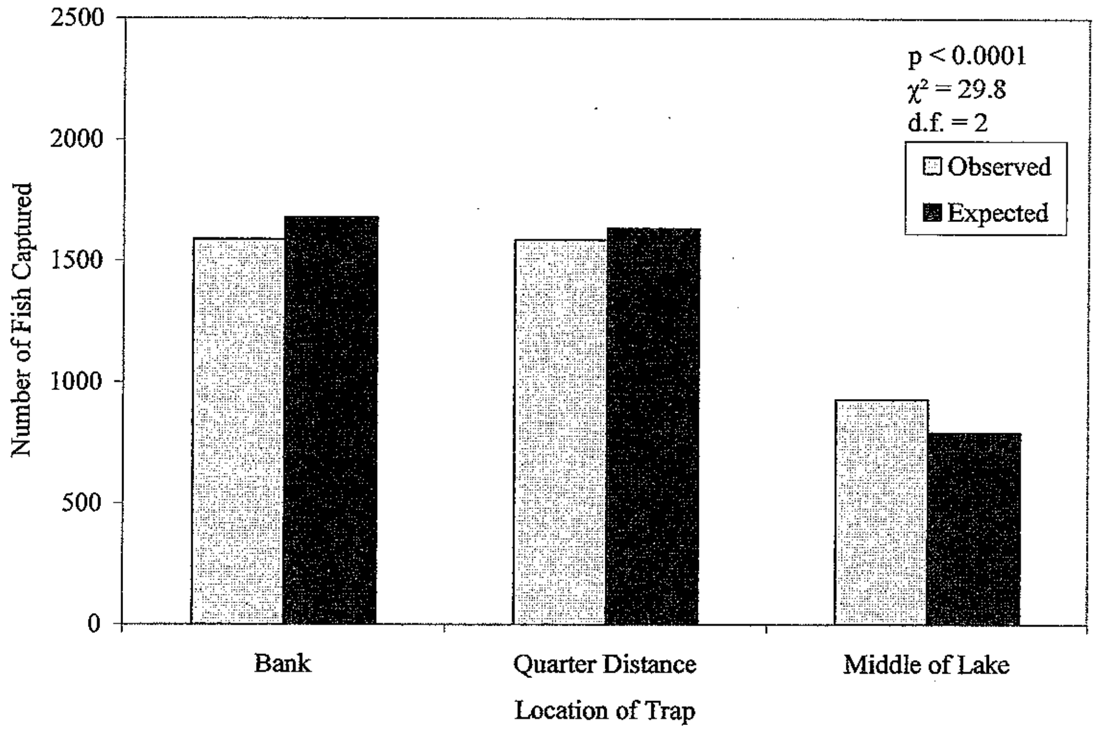

Figure 39. Number of Mohave tui chub captured at each trapping location within the lake during the October 2005 trapping period at Lake Tuendae. The number of captures per trap location, based on a proportion to account for the different amount of traps, was statistically compared to the number of captures that would be expected if fish were captured evenly within the lake, using a Chi-square test ($p < 0.001$).

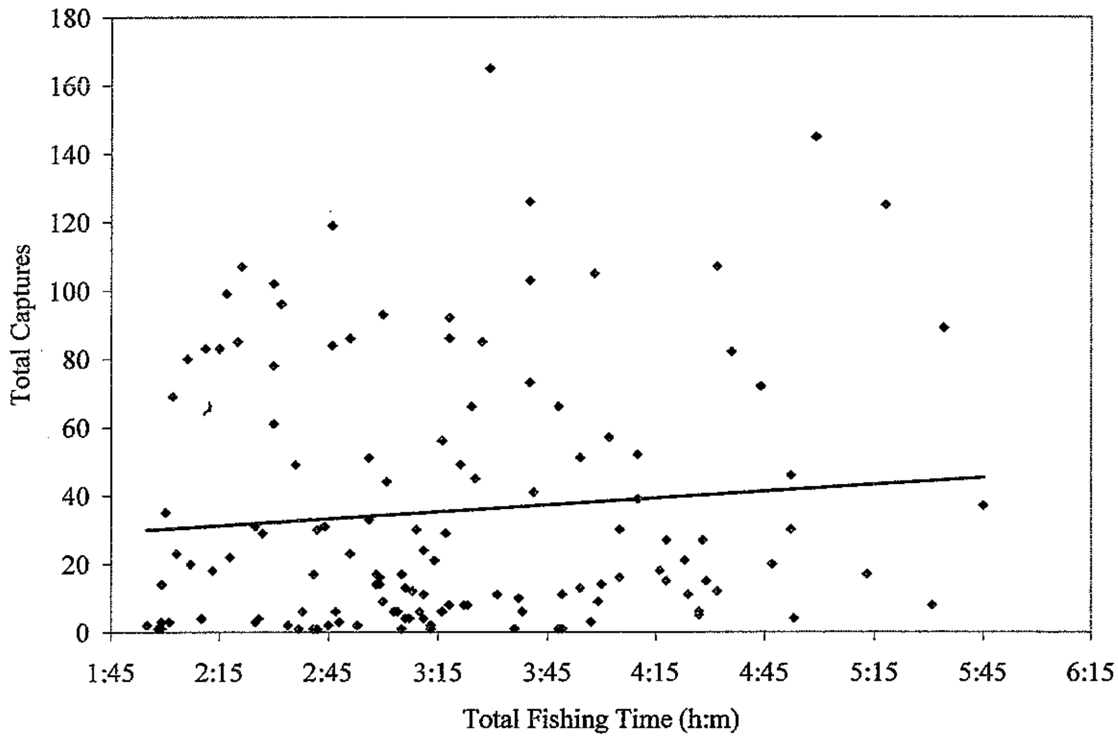

Figure 40. Total number of Mohave tui chub captured during the October 2004 trapping period at Lake Tuendae, compared to the total time traps were left fishing at each trap location (ANCOVA, P = 0.705; F = 0.14; d.f. = 127; R^2 = 0.34).

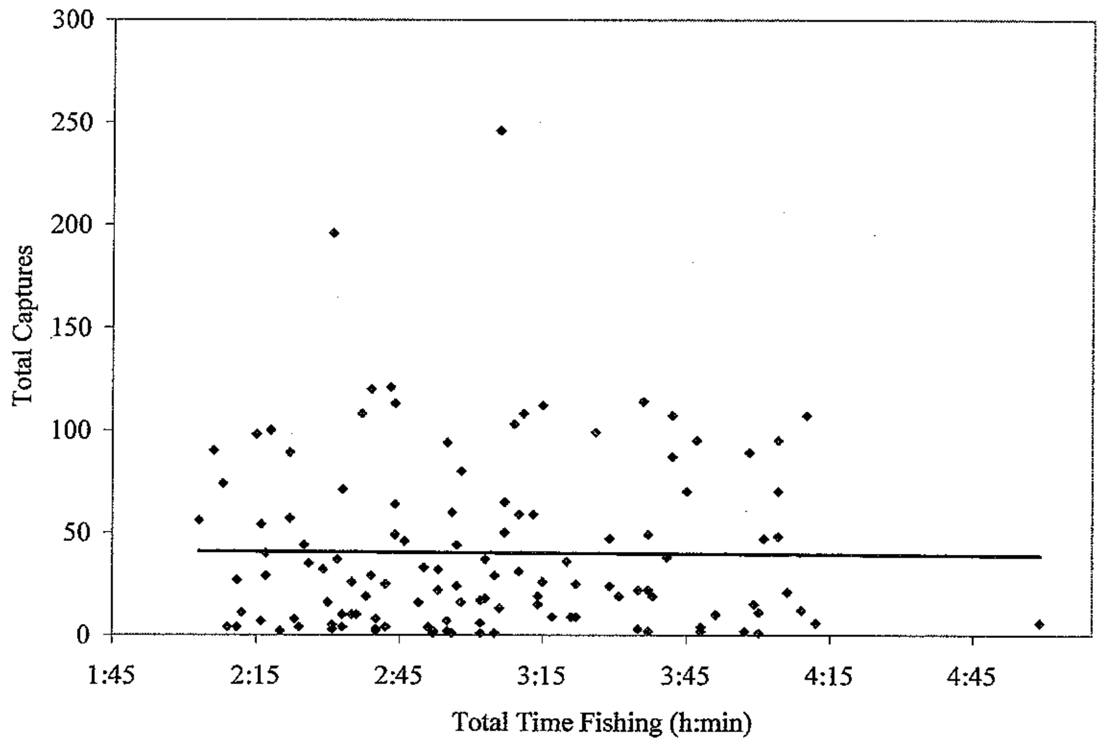

Figure 41. Total number of Mohave tui chub captured during the October 2005 trapping period at Lake Tuendae, compared to the total time traps were left fishing at each trap location (ANCOVA, P = 0.303; F = 1.07; d.f. = 120; R^2 = 0.0001).

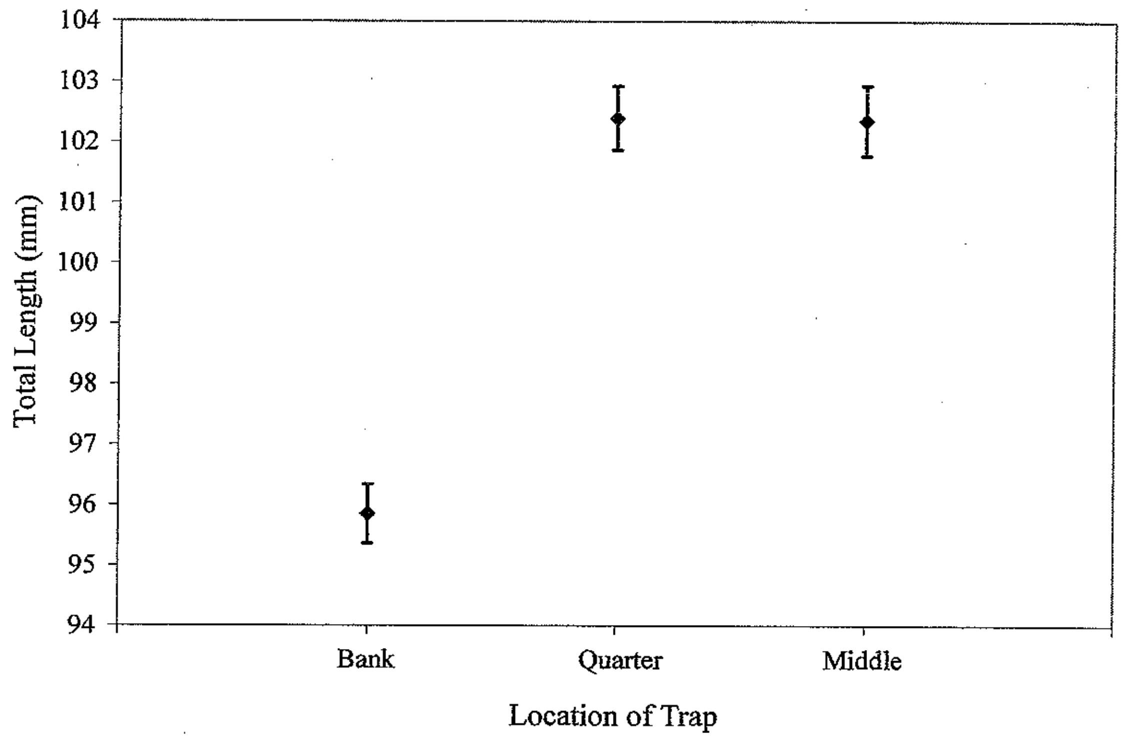

Figure 42. Mean (± SE) total length (mm) of Mohave tui chub captured among trap locations within the lake, during the October 2004 trapping period at Lake Tuendae. Mean total length was found to be significantly different between trap locations using an ANOVA ($P < 0.001$; $F = 40.05$; d.f. = 2).

Figure 43. Mean (± SE) total length (mm) of Mohave tui chub captured among trap locations within the lake, during the October 2005 trapping period at Lake Tuendae. Mean total length was found to be significantly different between trap locations using an ANOVA ($P < 0.001$; $F = 13.66$; d.f. = 2).

CHAPTER 4

DISCUSSION

Trapping methods for Mohave tui chub were modified from the April to the October trapping periods at Lake Tuendae. In comparing the length distribution captured by each trap type, the large minnow trap captured the greatest size range of fish (Figure 7). The large minnow trap also had the highest CPUE when compared to the other traps used (Table 6). Although the trap type with the second highest CPUE was the square one-hole trap, this trap did not capture a great length distribution of fish (Figure 8). The standard minnow trap captured a greater length distribution (Figure 9) and had the third highest CPUE. The large minnow trap and the standard minnow trap remained consistent for both October trapping periods. While the large minnow trap was most successful at capturing larger sized fish, the standard minnow trap was successful at capturing smaller sized fish. This allowed capture of a greater distribution of size classes for the population. Mesh size of these two trap-types remained standardized for all trapping periods (Table 1 and 3).

During the April trapping period, trapping stations received specific trap types at the start of the sampling and these traps remained stationary during the sampling period. If a trap did not capture fish well, or did capture a particular size class of fish, the trapping station, and hence the area of the lake the station was represented, would have an under representation of captures. Also, during the April sampling traps were just thrown into the lake and, depending on the throw, the traps distance from the bank varied. Most often were probably no more than 5-8 m out into the lake. For the October trapping periods, trap types were randomly moved between trapping stations, so that the same trap was not always trapping at the same station. Traps were also randomly placed at different locations within the lake. The October trapping design provided better coverage of all habitats in the lake. Due to the difference in trapping designs, captures from the standard minnow and large minnow traps were used to standardize certain analyses in comparisons with October 2004 and 2005 data.

For all analyses, the large minnow traps captured significantly more fish than expected, whereas standard minnow traps captured fewer than expected (Figures 6, 10, 11). This difference could be due to the different dimensions of these traps and the ability to capture different size ranges. Combining captures from both trap types, though, represents a broader depiction of the population as a whole. Therefore, these trap types were not separated for certain analyses.

Length-weight relationships are an important tool in managing fish populations, and in assessing overall condition of fish. While there is a significant difference in the length-weight relationships obtained for each collection period (Figure 24), these relationships may be used to compare future data. Although significantly different, Lake Tuendae (April and October) and Camp Cady have more similar relationships than China Lake (Figures 20 – 23). Comparing b constants in the length-weight equations, China Lake has a different growth proportional relationship.

It is presumed at Camp Cady, Mohave tui chub are not infected with Asian tapeworm. That Lake Tuendae has a similar length-weight relationship to Camp Cady may indicate that Asian tapeworm has not rapidly increased the weight of this population. Infections of Asian tapeworm have been shown to cause intestinal blockage and create lesions on the intestinal wall, resulting in distended stomachs of infected fish (Salgado-Maldonado and Pineda-Lopez, 2003). It is not known if China Lake Mohave tui chub are infected with Asian tapeworm. China Lake Mohave tui chubs may just have larger sized fish, data shows more frequently occurring and overall larger sized fish then Lake Tuendae and Camp Cady (Figure 26-30).

Weight can vary greatly depending on food availability, season or development (Ricker, 1971; Jobling, 2002). There can be wide variations in weight between fish of the same length both within and between populations (Jobling, 2002). In a 30-m^2 pond at the Desert Research Station in Barstow, Mohave tui chub lost weight from August to October, and then began to gain weight again (Havelka et al., 1982). Differences in weight could be due to different sampling times. More likely the high growth rate (b) for China Lake may represent error in the weights obtained for China Lake, which had a low sample size. According to Jobling (2002), the numeric value of b is usually close to 3, almost consistently between 2.5 and 3.5. Future studies should analyze length-weight relationships for the population at China Lake to determine if a growth difference truly exists.

Length-frequency distributions can reveal population dynamics over time. Fish hatched within the same year tend stay in the same size range relative to each other, growing in spurts during optimal conditions. These growth patterns influence size at age classes for a population. Plots of lengths of individuals should form normal distributions around a specific size-age class. There should be recognizable peaks in the size distribution of a population sample, as long as the sample is unbiased (Jearld, 1983).

Size-frequency distributions for fish in April 2004 (Figure 26), October 2004 (Figure 27), and October 2005 (Figure 28) are generally unimodal. These histograms do not form recognizable distributions around specific size-age classes. Vicker (1973) also noted that length frequency did not isolate groups by age. One factor for this distribution could be the growth rate for Mohave tui chub is approximately linear (Vicker, 1973; Taylor and McGriff, 1985). This could make it harder to identify age classes reliably from these histograms (Ricker, 1975). Another factor could be continuous growth for the first two years, as noted in Owens tui chub (*Siphateles bicolor snyderi*) (DFC, 1996). Also, spawning may possibly occur in both spring and fall months, creating overlap in age classes due to the subsequent different growth patterns (Vicker, 1973).

Shifts in length distributions can be followed across different sampling periods to document recruitment, growth or mortality (Jearld, 1983). One of the objectives of my study was to determine if there was successful juvenile recruitment in the Lake Tuendae Mohave tui chub population. Comparing the histograms for all trapping periods, the continuous presence of smaller size classes indicates some recruitment has occurred between samples. The number of smaller sized fish also increased, for example those in 60-69 and 70-79 mm size classes, from October 2004 to October 2005 (Figure 27, 28). The presence of smaller sized fish and the increase in the numbers of these size classes between sampling periods indicates successful juvenile recruitment likely occurred during the study period.

In these length-frequency distributions, the relative low number of smaller sized fish was due to an under-representation of smaller size classes. There should naturally be a larger number of smaller fish present in order for the population to sustain itself (Smith, 1990). Smaller-size class fish are not usually adequately represented in population studies and are considered not catchable (Ricker, 1975). This could be due to the small size of the fish relative to the sampling gear used, or younger, smaller, fish displaying different behaviors than those captured (Ricker, 1975).

To estimate an annual survival rate, catch curves were generated for all data collected during all trapping periods at Lake Tuendae. Because fish were not aged in this study, age classes established by Vicker (1973) were fit to lengths measured during Lake Tuendae trapping periods. Although, this assumes that there has been no change in growth patterns in these fish between these studies. Since changes in growth are probable over the time between these studies, these age classes are just an estimate. Estimated survival rates may provide baseline data for future comparisons. Continuous survivorship estimates could monitor overall population conditions over time.

Changes in growth rates over time may be evident in the differences of sized fish at particular age classes determined by Vicker (1973) and Taylor and McGriff (1985). Taylor and McGriff (1985) noted their data showed smaller size classes compared to Vicker (1973), possibly as a result of variation in food availability. During the 1970s, guests at Zzyzx Mineral Springs Resort threw scrap foods into Lake Tuendae, which may have artificially increased the growth of this population (Taylor and McGriff, 1985). By the 1980s, the resort was no longer in operation and the fish were left to rely on food produced in their habitat (Taylor and McGriff, 1985). Inaccuracy in age determination, though, will not affect the catch curve unless there is bias, which may occur as fish are aged. Usually a negative bias often occurs, as older individuals are assigned younger ages. If there is a strong bias, estimated survival rates may be too low (Krebs, 1989). The annual survival rate was higher for data reported by Vicker (1973) than the estimate obtained for Taylor and McGriff (1985).

Although survivorship in my study decreased by 15 % between April 2004 and October 2005, these estimates are higher than those obtained of Vicker (1973) by 5-21 % and Taylor and McGriff (1985) by 13-21 %. The increase of annual survival rates from previous years to current estimates may be a reflection of more active management and protection of this population. This may have allowed acclimatization to an undisturbed habitat and a dependence on natural food production.

Based on population estimates from each trapping period, the population size in Lake Tuendae increased from April 2004 to October estimates (Figure 37). This may be an increase in the population size or a reflection of the different trapping methods used in April 2004. The population estimate decreased from October 2004 to October 2005. While the 95 % CI from these estimates do not overlap, the similarity of intervals may indicate that it may be premature to conclude that population size decreased from October 2004 to October 2005.

Fluctuations in population size of this magnitude, however, may be natural. Taylor and McGriff (1985) reported a population estimate in October 1981 of 5,588 (95% C.I.: 4,314-7,929) and in February 1982 an estimate of 1,450 (95% C.I.: 1,251-1,725) Mohave tui chub in Lake Tuendae. Population cycles have been reported to occur in other fish species such as roach, salmon and vendace (Townsend et al., 1990). These cycles could be influenced by age of first reproduction, growth, inter-age-class competition, juvenile recruitment levels, and mortality (Townsend et al., 1990). Long-term studies would be needed to determine any trends in population levels over time.

Capture success was analyzed by comparing the number of captures at each trapping location in the lake for October 2004 (Figure 38) and October 2005 (Figure 39). Analysis of the number of captures at different locations indicates that fish were not equally captured throughout the lake. For both October trapping periods, the bank consistently captured fewer fish than expected and the middle captured more fish than expected. The size of fish captured at different locations also was significantly different for both October trapping periods (Figure 42, 43). The bank location captured smaller-sized fish compared to the quarter and middle locations for both trapping periods.

These differences suggest that different sized fish use different locations within the lake. This may be a function of different habitat requirements for fish of different sizes, or reflect niche partitioning to reduce inter-age-class competition. Sites for future recovery populations should offer a range of microhabitats to meet requirements of different life stages of the population.

Management Recommendations

My study has not shown convincingly that currently the Lake Tuendae population of Mohave tui chub is declining, although effects the introduced Asian tapeworm may have on this population remains largely unknown. Asian tapeworm negatively effects other fish populations, including some cyprinids (Salgado-Maldonado and Pineda-Lopez, 2003). At high infection levels, tapeworm may cause serious injury to fry and small fish, reduce growth rates and reproduction, and ultimately, increase mortality (Granath and Esch, 1983; Salgado-Maldonado and Pineda-Lopez, 2003). Future research is needed to determine any long term effects of this tapeworm on Mohave tui chub.

The presence of mosquito fish (*G. affinis*) in Lake Tuendae also poses a possible threat to the condition of resident tui chubs. The introduction of mosquito fish has been shown to negatively effect native fish populations. Survival rates of least chub (*Iotichthys phlegethontis*) decreased in the presence of mosquito fish (Mills et al., 2004). Predation by large mosquito fish may directly decrease population numbers. As a result, least chub find refuge in shallower waters, where intra-specific competition increases with younger least chub, and inter-specific competition increases with juvenile mosquito fish. These interactions decrease the overall fitness of the population (Mills et al., 2004).

The results of introductions of invasive species on native species depend on the number of simultaneous negative interactions (Mills et al., 2004). Mohave tui chub are faced with the introduction of two exotic species whose effects are unknown. Confronted with an exotic species, native species may be forced to trade fitness components for immediate survival, although decreased fitness decreases overall survival of a species

(Mills et al., 2004). Future research should address potential negative effects of invasive species and how to minimize these impacts for the protection of this endangered fish.

In 1984 the USFWS outlined a recovery plan of Mohave tui chub (USFWS, 1984). According to this report, reclassification requires the presence of at least six stable populations, each greater than 500 fish, and that these populations be located within the species historic range and remain free from any threats for five consecutive years. Although population estimates for both the April and October trappings show a population over 500 fish in Lake Tuendae, this population faces threats of introduced species. With the effects of the tapeworm and mosquito fish still unclear, continuous monitoring and proactive management are required to ensure the survival of this endangered species. An updated recovery plan should be established to re-evaluate criteria for reclassification of this species and establish current goals of recovery efforts.

In establishing current criteria for reclassification, one aspect to consider is the risk of extinction and the overall rarity of these desert fish. Rare species, or those that are sparse, or have a fragmented distribution, are therefore more vulnerable to extinction (Meffe et al., 1997; Fagan et al., 2002). Fagan et al. (2002) showed it was five times more likely for desert fish species with the most fragmented historic distributions to suffer local extinctions than those with more continuous distributions (Fagan et al., 2002). Although Mohave tui chub historically have a more continuous distribution, it may not be currently feasible to reintroduce this species to the Mojave River due to anthropogenic alterations. The hydrology of the Mojave River has been altered substantially in recent times (Smith, 2003), and headwater reservoirs and water diversions have decreased suitable habitat.

Fagan et al. (2002) indicated that, in the face of anthropogenic alterations of landscape, more compactly occurring spatial distributions may be more resistant to environmental change. This may suggests that a good strategy may be to maintain several strong, stable populations along the river. With a decrease in suitable natural habitat, artificial habitat could also be considered. Lake Tuendae, a man-made pond, has supported a rich population of Mohave tui chub for possibly as great as 50 years; if Springer introduced the fish when the pond was excavated. Recovery populations should still be considered outside of the historic range as well. Having numerous populations could only reduce the risk of extinction. For example, Mohave tui chub may have never been introduced to China Lake if only the historic range was considered. And the China Lake population of Mohave tui chub has thrived in this habitat for 35 years.

If future censuses consistently find large population sizes, Lake Tuendae could be a source for transplants elsewhere. Any plans to use Lake Tuendae fish to restock other populations must first resolve the issue of the Asian tapeworm. Future refugia should offer shallow areas with aquatic vegetation for the habitat requirements of younger fish, with open deeper waters for older, large sized fish. The results of my study documented different habitat use by different sized fish. Lack of a large enough habitat with shallow and deeper waters may be one of the various possible reasons that some of the past recovery populations failed.

CHAPTER 5

CONCLUSION

My results indicate there is a large population of Mohave tui chub at Lake Tuendae and that this population remained large across three trapping periods spanning 18 months. Successful juvenile recruitment has also apparently occurred between trapping periods. My results documented a difference in habitat use among different sized fish, and provided annual survival estimates, length-weight relationships and length-frequency distributions that may be used as a baseline for long term monitoring.

This study also demonstrated successful trapping method for Mohave tui chub at Lake Tuendae. My results compared trapping methods from two different designs and established the most effective traps (large minnow and standard minnow) at capturing the broadest size range of Mohave tui chub at Lake Tuendae, and a method to adequately sample the entire habitat.

It is also recommended that an updated recovery report for Mohave tui chub outline current conservation and recovery goals. Lake Tuendae could possibly be used to stock recovery population, if the issue of Asian tapeworm is resolved. Potential areas of future refugia need to be established and evaluated. In summary, continuous population assessment and habitat monitoring of existing populations and the establishment of additional recovery populations are key to the survival of this endangered fish.

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