State of California
The Resources Agency
DEPARTMENT OF FISH AND GAME

ORIGIN, STATUS, AND FUTURE MANAGEMENT OF THE COTTONBALL MARSH PUPFISH, *CYPRINODON MILLERI* (LA BOUNTY AND DEACON), IN DEATH VALLEY, CALIFORNIA

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Inland Fisheries Endangered Species

Program Special Publication 80-4

August 1980

LDA

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ORIGIN, STATUS, AND FUTURE MANAGEMENT OF THE COTTONBALL MARSH PUPFISH, CYPRINODON MILLERI (LA BOUNTY AND DEACON), IN DEATH VALLEY, CALIFORNIA[1]

by

Louis A. Courtois, Ph.D.[2]

ABSTRACT

The Cottonball Marsh pupfish, *Cyprinodon milleri*, is the most recently described species of cyprinodont from the Death Valley System. It is believed that *C. milleri* differentiated from a generalized pupfish progenitor, an original inhabitant of Lake Manly. This Lake at one time covered the entire floor of Death Valley. Subsequent drying and tilting of the Valley floor in the past 2,000 years has resulted in geographic isolation of many pupfish populations. This isolation combined with the environmental extremes common to Cottonball Marsh have resulted in differentiation of the progenitor pupfish into *C. milleri*.

The current State listing of "Rare" is an appropriate designation because, although not presently threatened with extinction, they occupy only one limited habitat in California. The National Park Service has proposed the Cottonball Basin be managed as a wilderness subzone which would afford the pupfish habitat security. Since this pupfish presently occupies its entire known range further management efforts need only be directed towards continued habitat protection with periodic monitoring of the population.

1/ Inland Fisheries Endangered Species Program Special Publication 80-4. This report was prepared as part of an Endangered Species Act grant-in-aid project, "California E-F-3, Endangered, Threatened, and Rare Fish."

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INTRODUCTION

The status of the cyprinodont fishes of the Death Valley System has changed dramatically since they were extensively studied and classified by Miller (1948). The species diversity is a result of environmental influences caused by changes in the hydrologic conditions within the system. A brief review of the known hydrologic changes which have occurred within the Death Valley System will provide a basis for understanding the present diversity of cyprinodont species within this area.

The Death Valley System ranks third in area and faunal diversity among the interior drainage basins (Hubbs and Miller 1948). The system drains desert regions of eastern California and adjoining parts of western Nevada (Figure 1). Historically this area includes drainage from the Mojave Desert, Amargosa Desert, Owens Valley, Searles Lake, Panamint Basin, Lake Pahrump, and Adobe Valley. Hubbs and Miller (1948) estimated the native fish fauna of this system to consist of 3 families, 5 genera, 10 species - at least 24 kinds in all.

At one time all these areas drained into the large freshwater terminal lake, Lake Manly (Figure 1), which covered most of Death Valley (Soltz and Naiman 1978). Blackwelder (1933) was the first to accurately describe and map Lake Manly, although the existence of a Pleistocene lake in Death Valley was recognized before the turn of the century by Russel (1885, 1889) and Gilbert (1890). Lake Manly, at its maximum height was about 160 kilometers (km) long, 10 to 17 km wide, and 185 meters (m) deep. Fishes and other aquatic organisms abounded in this large inland lake. Following the pluvial period (8,000 to 12,000 years ago) the area began drying, resulting in several lakes desiccating while others shrank and became more salty.

Approximately 4,000 to 8,000 years ago the climate became more arid which caused many of the water courses to disappear, leaving the desiccated remnant habitats present today. As the waters receded, fish were forced into spring-fed pools and small desert streams. The only endemic fish species which could adapt to the extremes in environmental temperature, salinity, and the limited food supply were the killifish. This all occurred over a relatively short period of geologic time - a few thousand years (Bunnell 1970).

Today all that is left of Lake Manly are three basin areas: Cottonball Basin, Middle Basin, and the Badwater Basin (Figure 2). The Cottonball Basin contains Cottonball Marsh and Salt Creek which continues through the Middle Basin until it evaporates. The Amargosa River flows west into Death Valley south of Shoshone, then north to empty into the Badwater Basin, where it eventually evaporates. Badwater is one of the lowest points in Death Valley (85 m below sea level). There has been at least one instance (Alley et al. 1971) when pupfish common to the Amargosa River have been found in Death Valley at Badwater. This occurrence could have been the result of either a "coffee-can" transplant by an unknown visitor to the monument, or by a floodwater connection to Badwater as yet undocumented.

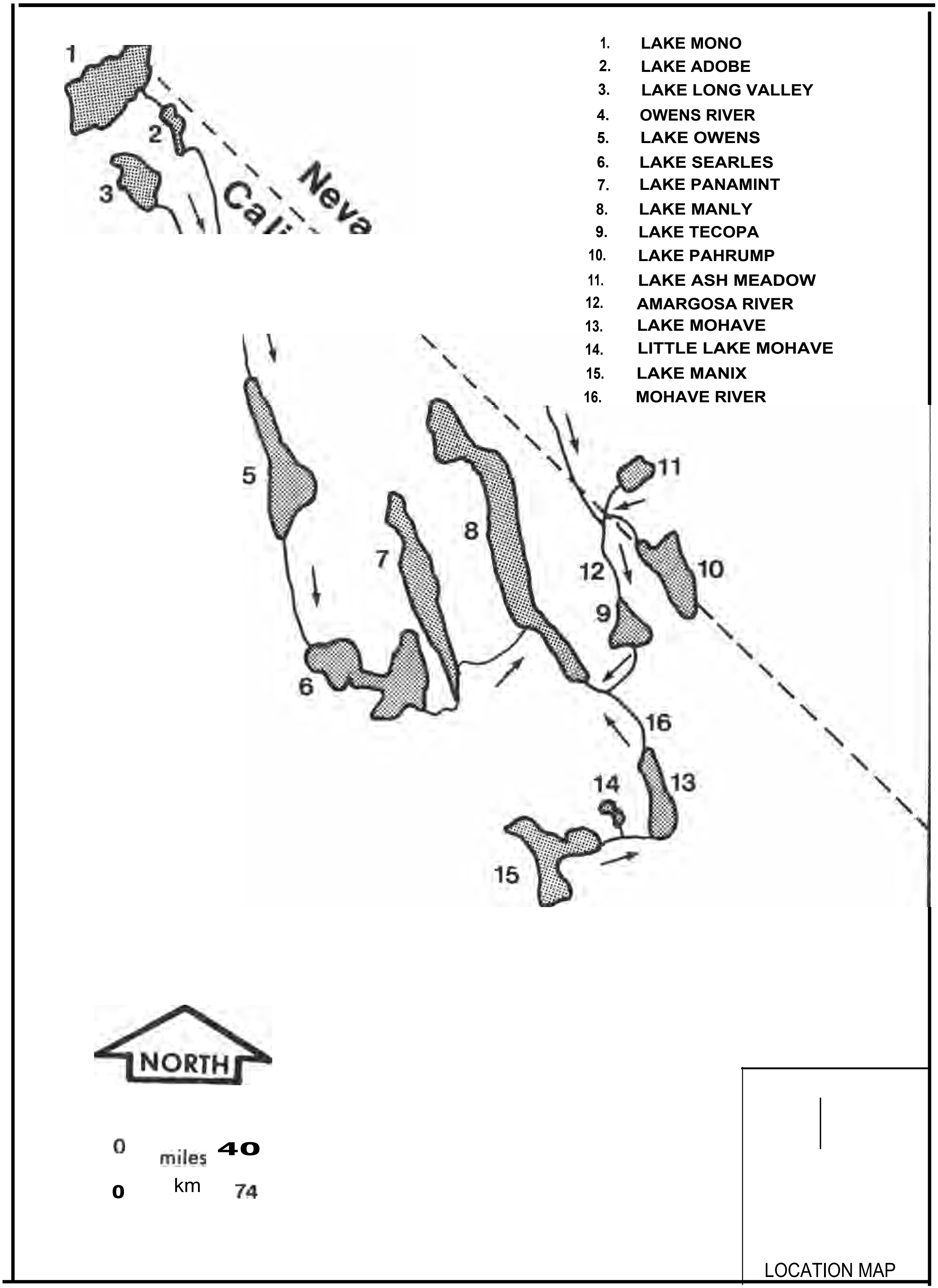

FIGURE 1. Major pleistocene waters within the Death Valley System (adapted from Hubbs and Miller 1948).

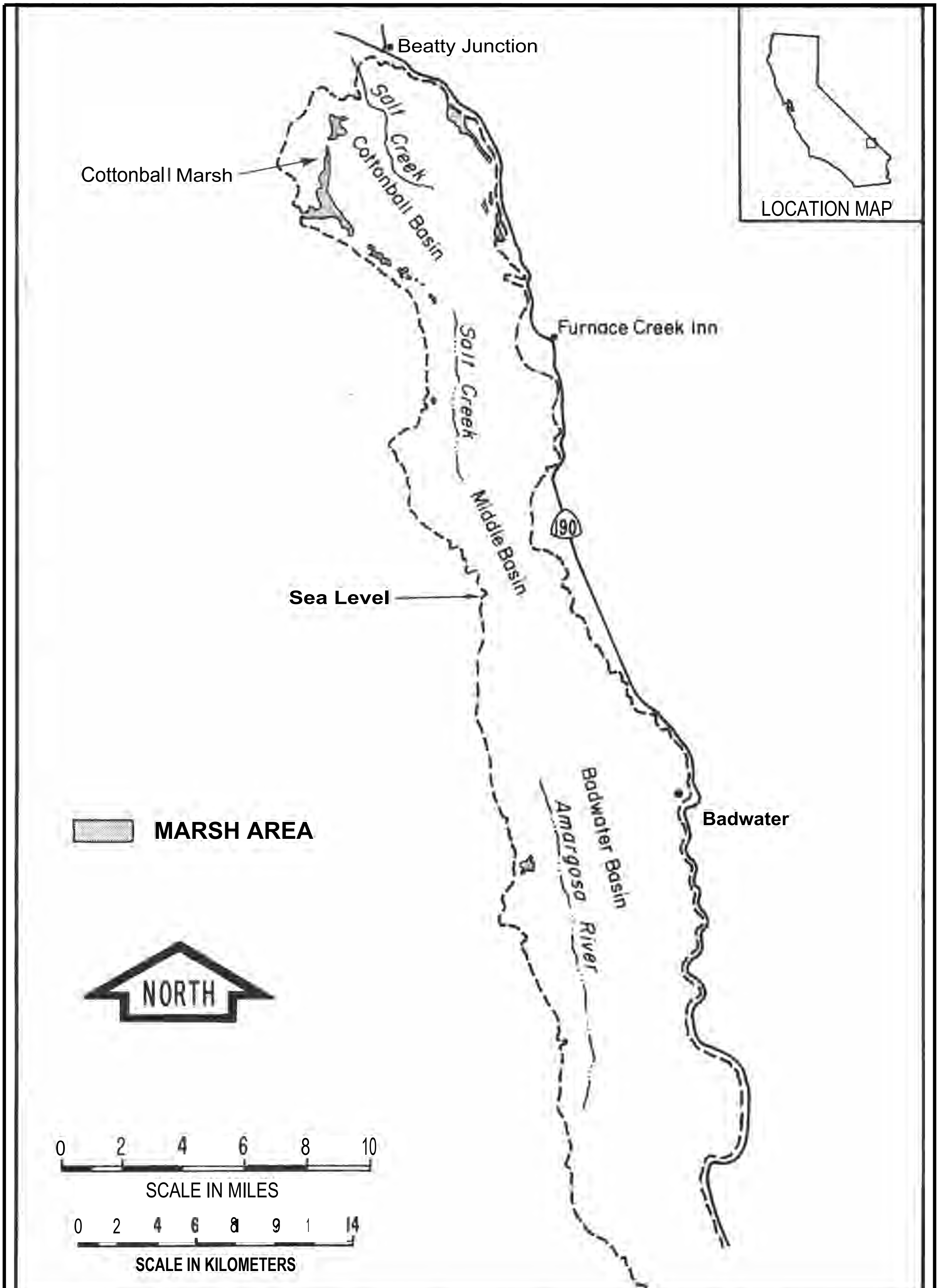

FIGURE 2. Existing basins within historic Lake Manly.

One of the most recently described fish species from the Death Valley System is the Cottonball Marsh pupfish, *Cyprinodon milleri.* This pupfish was described as a new species of cyprinodont by La Bounty and Deacon (1972) several years after its original discovery in the early 1960's (Hunt et al. 1966). La Bounty and Deacon (1972) studied this pupfish and its harsh environment for over 6 years prior to publishing their results and proposing the pupfish as a distinct taxon. Today this fish lives in one area, Cottonball Marsh, which is part of Death Valley National Monument. The entire population of *C. milleri* resides in the salt ponds and channels located within the 260 hectares (ha) of Cottonball Marsh. This Marsh lies 80 m below sea level in the north-central area of Death Valley on the west side of the salt pan. It has been classified as a rare species by the California Fish and Game Commission since 1974 because of its limited distribution. This report summarizes what is presently known about this species and proposes a joint fisheries management program for its preservation.

NOMENCLATURE

Cyprinodon salinus, Hunt et al., 1966[3/]
Cyprinodon sp., La Bounty, 1968[4/]
Cyprinodon salinus, Brown, 1971
Cyprinodon sp., Brown and Feldmeth, 1971
Cyprinodon milleri, La Bounty and Deacon, 1972
Cyprinodon sp., Otto and Gerking, 1973
Cyprinodon milleri, Naiman et al., 1973
Cyprinodon sp., Deacon and Minckley, 1974
Cyprinodon milleri, Moyle, 1976
Cyprinodon milleri, Naiman et al., 1976
Cyprinodon milleri, Soltz and Naiman, 1978

DESCRIPTION

La Bounty and Deacon (1972) originally described both the holotype (UMMZ 188995) and paratypes (UMMZ 188996). The following data are taken from their description of the holotype:

> Length to base of caudal 28.1 millimeters; predorsal length .613; prepelvic length .579; anal origin to caudal base .312; greatest depth of body .346; greatest width of body .230; length of head .291; depth of head .306; width of head .234; length of caudal peduncle .218; depth of caudal peduncle .154; width of interorbital area .092; length of snout .074; length of orbit .087; width of mouth .101;

[3/] These authors assumed all pupfish within the Cottonball basin to be the same species. No taxonomic data collected.

[4/] Thesis which first alluded to the uniqueness of this population.

length of postorbital area .140; length of upper jaw .084; length of dorsal fin base .128; length of anal fin base .097; height of dorsal fin .227; height of anal fin .234; height of middle caudal fin rays .202; length of longest pectoral fin ray .211; length of longest pelvic fin ray .064; scales in the lateral series 29; scales from dorsal origin to anal origin 14; scales from dorsal origin to pelvic insertion 14; scales around caudal peduncle 20; predorsal scales 28; scales around body 40; pelvic fin rays 5; dorsal fin rays 8; anal fin rays 9; pectoral fin rays 15; caudal fin rays 15; gill rakers 19; preorbital pores 2; preopercular pores 14; vertebrae 27.

Sexual dimorphism exhibited in C. *milleri* is similar to other Death Valley pupfishes. According to La Bounty and Deacon (1972) males are usually larger, have deeper bodies, heads, and caudal peduncles, have dorsal and pelvic fins positioned more anteriorly than in females (Figure 3), and have a larger anal fin. Preserved males have 7 to 8 broad, vertical bars extending downward from a darkened dorsum to a lighter colored belly. Females also have 7 to 8 vertical bars on the sides, but narrower and more distinct than on the males and usually wedge-shaped, with the broader portion dorsal. The dorsal fin is blackened in males as are the distal margins of the pectoral, anal, and caudal fins; the pelvic fins are clear in life. Milky white pigmentation occurs in the proximal and middle parts of the pectoral, anal, and caudal fins. By contrast, the female's dorsal fin displays interrupted black blotches in the anterior interradial membranes, and a distinct ocellus near its posterior base. Caudal, anal, pelvic, and pectoral fins are transparent to translucent, without any darkening of their margins. Life colors of breeding males range from a deep blue on the sides to an iridescent turquoise on the sides of the head and dorsal fin. The venter of both sexes is milky white at all times of year.

There are several general characteristics which distinguish C. *milleri* from other closely related species (Table 1): (1) shorter pelvic fins with fewer rays (except for C. *diabolis* which lacks pelvics); (2) lower ray counts on all other fins; (3) higher scale counts – most closely resembling C. *salinus*; (4) the number of gill rakers is intermediate between C. *nevadensis* and C. *salinus;* (5) caudal peduncle length shorter and more slender than all other species, except C. *diabolis*; (6) structure of jaw teeth similar only to C. *salinus;* (7) higher number of scales between dorsal and anal origins; (8) higher number of scales between dorsal origin and pelvic insertion; (9) higher number of scales around the caudal peduncle; (10) higher number of predorsal scales; (11) higher number of scales around the body; and (12) fewer or no preorbital pores (La Bounty and Deacon 1972; Moyle 1976).

TAXONOMY

Geological surveyors within the Death Valley Monument during the 1960's recorded the presence of several isolated populations of pupfish within the perennial pools of Cottonball Marsh and nearby Salt Creek (Hunt et al. 1966). Although geographically isolated from each other the pupfish were assumed to belong to the same species, C. *salinus*.

FIGURE 3. Cottonball Marsh pupfish, *C. mineri*. Male middle left, females top and bottom right.

TABLE 1. Comparison of Major Morphological Characteristics Among Four Western Pupfish Species: + = Present or Common, - = Absent or Rare (from Turner 1974; Moyle 1976).

Character	C. *radiosus*	C. *nevadensis*	C. *salinus*	C. *milleri*
Pelvic fins	+	+	+	+
Pelvic fin formula	7-7	6-6	6-6	0 to 7
Fin rays				
Anal	10.39 ± .04	10.04 ± .01	9.91 ± .03	9.61 ± .06
Caudal	17.03 .08	17.87 - .03	16.80 - .06	16.00 - .08
Dorsal	11.09 ± .05	9.90 ± .01	9.50 ± .05	9.13 ± .08
Pectoral	14.06 ± .04	15.91 ± .01	15.83 ± .08	14.61 ± .11
Pelvic	6.90 ± .02	5.21 [sic]	5.94 ± .04	3.48 ± .31
No. scales around body	27.94 ± .12	24.24 ± .06	38.16 ± .25	39.40 ± .31
Lateral series scales	26.60 - .05	25.53 - .02	28.89 - .15	29.84 - .21
Scales between dorsal and anal origin	10.25 - .06	9.02 - .02	12.08 - .17	13.60 - .17
Scales between dorsal origin and pelvic insertion	10.83 - .07	9.67 - .02	13.96 - .11	14.50 - .14
Scales around caudal peduncle	16.00 ± .03	14.95 [sic]	19.77 ± .09	20.00 ± .14
Predorsal scales	17.92 ± .11	17.99 ± .03	25.83 ± .13	28.85 ± .27
Projections on scale circuli	-	-	-	-

TABLE 1 (Contd)

Character	*C. radiosus*	*C. nevadensis*	*C. salinus*	*C. milleri*
Preorbital pores	3.59 [sic]	5.40 [sic]	$6.02 \pm .08$	$1.70 \pm .21$
Vertical bars on female	+	+	+	+
Pattern of female vertical bars	Disrupted	Disrupted	Continuous	Continuous
Caudal peduncle	Thick	Thick	Slender	Slenderer
Mature male body shape	Deep	Deep	Slender	Deep
Median ridge on tricuspid teeth	-	-	-	-
Shape of central cusp on tricuspid teeth	Truncate	Truncate	Spatulate	Spatulate
Relative size of central cusp	Broad	Narrow	Broad	Narrow

1/ Adapted from Miller (1948), Liu (1969), and La Bounty and Deacon (1972).

Miller (1945) was the first taxonomist to discuss the origins of the Death Valley fish fauna. Fossil evidence confirmed the existence of an ancestral *Cyprinodon,* a genus still common to the system. Hubbs and Miller (1948) thought the ancestral "*Cyprinodon* which inhabited Lake Manly constituted a single kind and the differentiation of this form, therefore, dates from the disappearance of the Lake and the consequent isolation of the ancestral stock in Salt Creek and in the lower Amargosa River."

The lower Amargosa River population occupying the southern end of Death Valley became *C. nevadensis* and gave rise to a number of distinct subspecies *(C.* n. *nevadensis, C. n. shoshone, C. n. calidae, C. n. amargosae, C. n. mionectes,* and *C. n. pectoralis,* Moyle 1976). The Salt Creek population which occupied the northern end of Death Valley eventually became *C. salinus* from which *C. milleri* differentiated (La Bounty and Deacon 1972).

The closest species of cyprinodont, both geographically as well as taxonomically, to *C. milleri is C. salinus* (La Bounty and Deacon 1972). Although these two species have historically shared a common basin, recent tilting of the Valley floor and uplifting along the Kit Fox Hills Fault has caused the two pupfish populations to become isolated from one another (Hunt et al. 1966; Hunt and Mabey 1966). The floor of Death Valley has also tilted eastward 6 m in the last 2,000 years (Hunt 1960). This, combined with the uplift along the Kit Fox Hills Fault, has resulted in recent diversion of Salt Creek from Cottonball Marsh. Subsequently the isolated pupfish population within Cottonball Marsh has differentiated into *C. milleri.* The taxonomic closeness of *C. milleri* to *C. salinus* reflects the common ancestry based upon known geologic changes within the basin (Table 1).

The short period of geographical isolation between *C. milleri* and *C. salinus* combined with the environmental differences in salinity (30 to 35 /oo for Salt Creek and 14 to 160 /oo for Cottonball Marsh) have caused morphological differentiation between the two species (La Bounty and Deacon 1972). Miller (1950) reported salinity to have the same effect on meristic characters as cold temperatures. La Bounty and Deacon (1972) compared several salinity-related meristic differences among three cyprinodonts of Death Valley (Table 2). Basically, elevated salinity was correlated to increases in scale number and decreases in the number of fin rays. The scale counts which show a mean increase with increasing salinity are: dorsal to anal origin; dorsal origin to pelvic insertion; circumference of caudal peduncle; circumference of body; lateral line series; and predorsal. Fin ray counts, which seem to show a decrease with increasing salinity, are: dorsal, anal, caudal, and pectoral. Hubbs (1940) described speciation as an "...orderly adjustment under the control of environment." He further stated speciation could occur very rapidly, especially when there are extremes in major environmental factors. La Bounty and Deacon (1972) suggest the development of *C. milleri* as a species to have occurred subsequent to the last permanent water connection between Cottonball Marsh and Salt Creek. This would be a relatively short time span - a few thousand years at most.

FIGURE 4. Cottonball Marsh, Death Valley National Monument, California.

TABLE 2. Relationship Between Salinity and Meristic Characters of Three Species of *Cyprinodon* from the Death Valley System. Data are Presented as $\bar{x}$ ± Standard Error. Environmental Salinity Increases from Left to Right.[1]

Character	Environmental salinity			
	0 - 30 $^{o}/oo$	30 - 35 $^{o}/oo$		14 - 160 /oo
	C. *nevadensis*	C. *salinus*		C. *milleri*
INCREASING TRENDS		Upper Salt Creek	Lower Salt Creek	
Scales				
Dorsal to anal	9.02 ± .02	12.50 ± .17	13.19 ± .08	13.60 ± .17
Dorsal to pelvic	9.67 ± .02	13.47 ± .13	14.13 ± .08	14.50 ± .14
Body circumference	24.24 ± .06	38.16 ± .25	38.36 ± .19	39.40 ± .31
Caudal peduncle circumference	14.95	19.20 ± .15	19.65 ± .11	20.00 ± .14
Lateral series	25.53 - .02	29.07 - .28	28.57 - .17	29.84 - .21
Predorsal	17.99 - .03	26.97 - .22	26.74 - .27	28.85 - .27
DECREASING TRENDS				
Fin Rays				
Dorsal	9.90 ± .01	9.50 ± .09	9.60 ± .10	9.13 ± .08
Anal	10.04 ± .01	9.93 ± .07	9.84 ± .08	9.16 ± .06
Pectoral	15.91 ± .01	15.83 ± .08	15.94 ± .15	14.61 ± .11

TABLE 2 (Contd)

Character	Environmental salinity			
	0 - 30 ^{o}/00	30 - 35 /oo		14 - 160 ^{o}/00
	C. nevadensis	*C. salinus*		*C. miZleri*
		Upper Salt Creek	Lower Salt Creek	
Caudal	17.87 $\pm$ .03	17.50 $\pm$ .16	16.95 $\pm$ .08	16.00 $\pm$ .08

[1/] Adapted from La Bounty and Deacon 1972.

HABITAT

General

Cottonball Marsh is the largest Marsh on the floor of Death Valley. The Marsh derives its name from the "cottonball" shaped mineral deposits, consisting of the borate minerals uloxite and probertite, which form around the periphery of the Marsh (Figure 5). The floor of the Marsh consists of a crust of salt and gypsum. The high salinity near the pools limits terrestrial plants to clumps of pickleweed *(Allenrolfea occidentalis)* and salt grass *(Distichis stricta)* which occur around the margins of the salt crust. Other forms of terrestrial vegetation grow higher up on the alluvial fan near seeps. Aquatic emergents *(Ruppia martima* and *Juncus* sp.) also occur in the less saline, more permanent water portions of the Marsh.

The Marsh itself consists of two separate areas of surface water. The smaller area is 56.7 ha and the larger located about 1 km south of the smaller, is 202.5 ha. Water covers approximately 40% of the total Marsh area in the winter but only 10% in the summer. The salinity at various locations around the Marsh ranges from 14 /oo (Naiman et al. 1973) to 160 /oo (La Bounty and Deacon 1972).

Pools contain lumpy translucent growths of gypsum, a few centimeters (cm) in diameter, coated by sodium chloride (Figure 5). In dry seasons, sodium chloride is deposited; in wet seasons the chloride is flushed out of the system and gypsum or other sulfate salts are deposited. Some pools have diameters up to 20 m but may be only 2 to 10 cm deep while other pools may reach a depth of 80 cm. Salt encrusting algae occur in the pools along the edge and create a surface for salt deposition, forming partial roofs (Figure 5). The pools are interconnected by channels approximately 1 in wide and 35 to 40 cm deep (Figure 6). Salt may even encrust over the deeper portions of channels, forming tunnels and shaded areas, and may also form islands in the pools and channels (Figure 4).

Aquatic Flora

Hunt and Durrell (1966) intensively sampled the major flora of the Death Valley region. At Cottonball Marsh they found algae growing in layers on the bottom of the translucent lumps of gypsum. The species found included *Anacystis montana, Microcoleus vaginatus,* and four species of *Phormidium.* In the dry season the water in the Marsh has a nearly neutral pH but the algae layers were distinctly alkaline, apparently because the algae create their own life zone with the necessary alkaline pH to sustain them. Hunt and Durrell (1966) also reported finding *Phormidium tenue* and *Anabaena variabilis* on crusts of sodium chloride. The "cottonballs" were also found to contain an algae *Coccochloris stagnale.* The salty water in which algae were found had an osmotic pressure up to 50 atmospheres. Sea water, which contains 33% salt, has an osmotic pressure of slightly under 20 atmospheres. Almost all species of algae found in the Cottonball Marsh were blue-green, with the exception of *Anacystis montana,* a green algae.

FIGURE 5. Salt-encrusted pool at Cottonball Marsh, Death Valley National Monument, California, being used by *C. milleri*.

FIGURE 6. Interconnecting channels at Cottonball Marsh, Death Valley National Monument, California.

Hydrology and Water Quality

The surface water supplying Cottonball Marsh is thought to originate in Mesquite Flat which is 8 to 16 km NW of Cottonball Marsh and is 328 cm higher in elevation. Hunt et al. (1966) surveyed the geology and hydrology of the upper Death Valley Basin and presented the following description: "Mesquite Flat is separated from the Marsh and from the rest of the Cottonball Basin by the Salt Creek hills, which represent a structural uplift of impervious upper tertiary beds belonging to the Furnace Creek Formation. A gorge through the hills enables surface water to discharge from Mesquite Flat to Cottonball Basin, but upstream, ground water is ponded in the structural depression under Mesquite Flat. This groundwater reaches the surface and discharges as perennial flow of Salt Creek in the gorge through the Salt Creek hills. This surface water discharges 4.8 km northeast of Cottonball Marsh and does not reach any part of the Marsh area proper."

Along the west edge of Salt Creek a fault trends almost south to Cottonball Marsh from the head of the perennial stretch of Salt Creek (Figure 7). Part of the groundwater ponded under Mesquite Flat probably discharges (flow estimated at 44 ℓ/s) southward along this and related faults to the Marsh, accounting all or in part for the large quantity of water at the Marsh (Hunt et al. 1966). This interpretation is supported by the similarity in chemical composition of the groundwater beneath the southern boundary of Mesquite Flat and at the Marsh (Table 3). The waters at both locations are alike in the relative proportions of Ca, Mg, Na, K, HCO_3, SO_4, As, Sr, F, and Cl, but differ in the proportions of boron and radium. The elevation in boron level at the Marsh seems reasonable since the Marsh groundwater inflow passes through a fault in the boron-bearing Furnace Creek formation.

LIFE HISTORY AND ECOLOGY

Water temperatures within the pools at Cottonball Marsh vary from near freezing in the winter to nearly 40°C in the summer (Naiman et al. 1973). The shallow water in the pool areas may fluctuate as much as 15°C each day, but the deeper channel areas fluctuate only 2 to 3°C per day. Although *C. milleri* exists in an environment that undergoes extremes in daily temperature, the fish themselves are able to avoid heat stress. If the pool temperature becomes too high, the fish simply move into the deeper, cooler (32°C) channel water (Naiman et al. 1973). Channel water is cooler because it arises underground from Mesquite Flat. Naiman et al. (1973) studied the thermal environment of Cottonball Marsh. They attributed the relatively cooler water temperatures to three physical processes: (1) the high evaporation rate, (2) the low desert humidity, and (3) the limited air movement. *C. milleri* can tolerate an upper maximum temperature of 43°C (Otto and Gerking 1973) which is similar to other species of cyprinodont (Brown and Feldmeth 1971).

Because of the annual recorded extremes in environmental salinity (14 to 160 °/oo) the Cottonball Marsh pupfish must have a high tolerance to changes in salinity. Naiman et al. (1973) observed water level

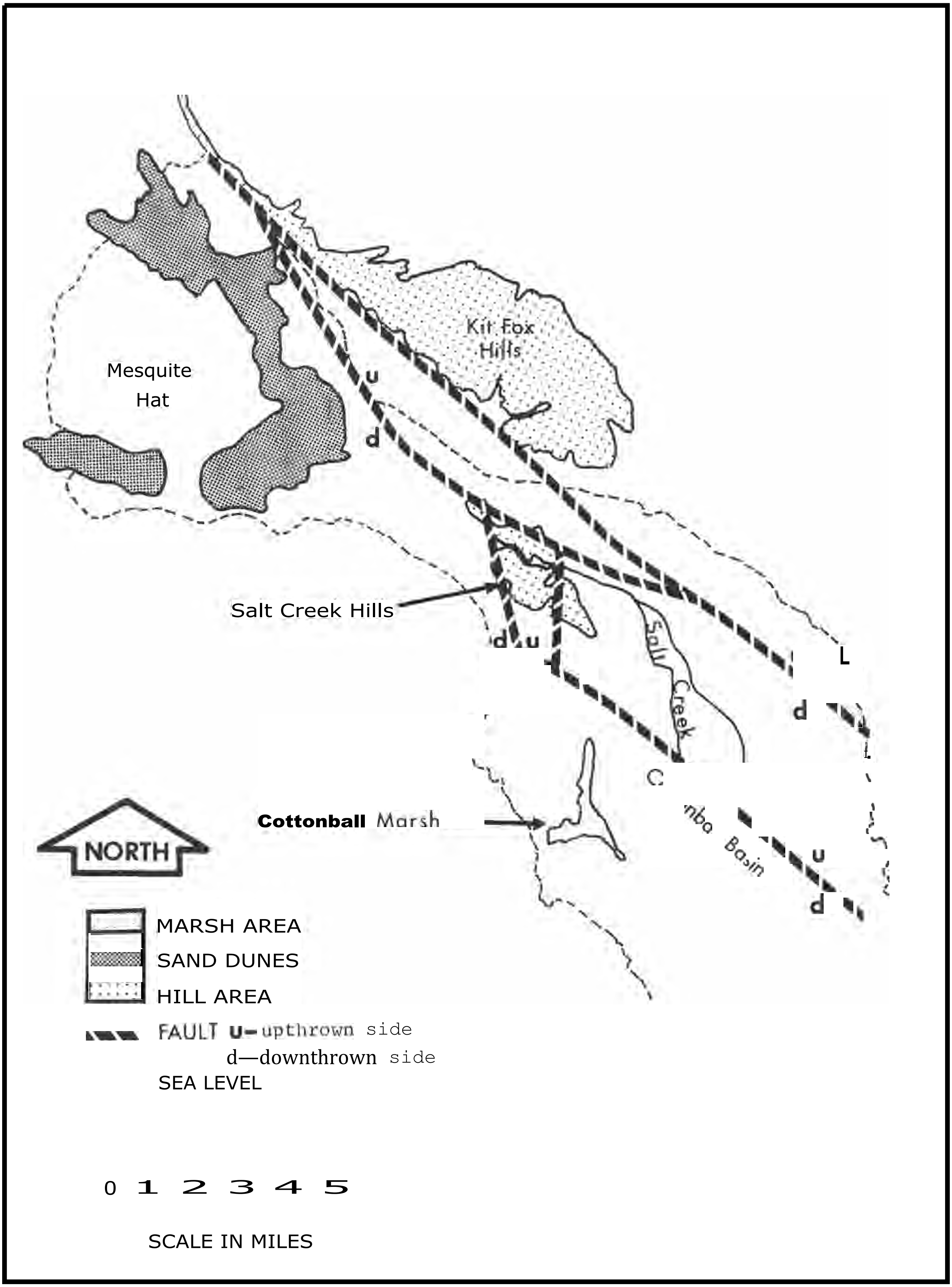

FIGURE 7. Existing faults in the Cottonball Basin which physically separates Cottonball Marsh from Salt Creek.

TABLE 3. Water Quality Analyses (Mg/ℓ) from Mesquite Flat and Cottonball Marsh.[1]

Element	Mesquite Flat	Cottonball Marsh
Ca	129	343
Mg	164	71
Na	2780	4480
K	219	250
HCO3	768	773
SO_4	1730	1600
Cl	3430	6290
As	0.04	0.04
Sr	11	6.0
F	2.4	3.1
B	8.0	30
0-phosphate	0.35	0.17
pH	7.6	7.0

[1] From: Hunt et al. 1966.

fluctuations in isolated pools over 2 to 3 day periods. These changes were caused by high evaporation rates and subsequently exposed resident pupfish to elevated salinities (Naiman et al. 1976). As already discussed (see Taxonomy), this appears to be the most important factor for the rapid differentiation of this species. No other species of pupfish inhabits such a saline environment. Even the desert pupfish, *C. macularius,* inhabiting the shoreline pools of the Salton Sea, rarely survives salinities over two timts that of seawater (Barlow 1958).

Diurnal changes in temperature although extreme do not appear to be a major factor influencing *C. milleri.* Naiman et al. (1973) monitored water temperatures throughout the Marsh and concluded *C. milleri* was always well below (10 to 15°C) its critical temperature maximum, even on the hottest summer days. By contrast, *C. salinus* and *C. nevadensis* are exposed to stressful water temperatures. Both Salt Creek and the Amargosa River are shallow and flow for miles. Because these two habitats have a large surface to volume ratio there is sufficient time for the water to equilibrate with the climatic conditions. Also, the fish are prevented from readily moving to areas of deeper, cooler water by waterfall barriers and distance.

There are several other organisms which live among the algae and bottom sediments in the pools and channels at Cottonball Marsh. These include: a hydrobioid snail *(Tryonia* sp.), an amphipod *(Hyalella azteca),* and an unidentified ostracod (La Bounty and Deacon 1972). Moyle (1976) believes the pupfish feed on these organisms as well as the algae. However, there are no published studies on food habits of *C. milleri.*

MANAGEMENT

The California Department of Fish and Game (DFG) and the National Park Service (NPS) already cooperate under a formal Memorandum of Understanding. This agreement provides broad guidelines for the cooperative management of all species of fish and wildlife occurring on NPS lands, and provides an operational framework for management of *C. milleri.* Briefly, its provisions include: (1) consultation between the DFG and NPS prior to initiating any action that may affect management, distribution, abundance, or species found on NPS lands; (2) cooperation between the DFG and NPS to enforce federal and State laws on NPS lands; (3) assistance from the DFG to the NPS for maintaining natural wildlife populations on NPS lands; (4) establishment of a technical study committee to jointly study fish and wildlife problems and develop recommendations for long-range and annual fish and wildlife programs; (5) exchange of information between the DFG and NPS for the wise use and perpetuation of regional fish and wildlife resources; and (6) development of supplemental agreements as necessary to carry out specific research or management programs. The specific management needs of the Cottonball Marsh pupfish are not addressed by the foregoing Memorandum of Understanding but they will be set forth in this report, which will serve as a basis for carrying out a joint management program for the Cottonball Marsh pupfish.

The most important objective in managing *C. milleri* is to maintain existing habitat integrity. Two critically important factors affecting this objective are water flow to the Marsh and protection of the fragile Marsh habitat. Water flow to the Marsh should be monitored quarterly to establish annual water flow patterns and to determine if reductions are occurring. This could be accomplished by placing staff gauges in several pools throughout the Marsh. The first 10 years of monitoring would serve as a baseline.

Visitor impact to Cottonball Marsh has historically been so low as to be considered nonexistent. The fragile nature of the Salt Marsh and the associated flora and fauna must be kept intact. Legal protection of the fragile Marsh terrain can be achieved by legislation establishing this area as wilderness (USDI 1976). A wilderness recommendation has been submitted to Congress but no action has been taken to date. Present access to the Marsh is limited to one jeep trail. The Superintendent controls the use of this unmarked trail, which is restricted to administrative use only and closed to the public. The trail can be used for access to the Marsh for research purposes, but this requires a special NPS permit.

Currently the NPS conducts periodic flights over the Marsh to monitor existing conditions. Because of the salt substrate any unauthorized vehicle or human tracks into the Marsh can be easily seen from the air. This monitoring program should continue as it has no impact on the habitat and is the fastest method to assure habitat security. The NPS also maintains daily surveillance of the Marsh from patrol vehicles, a practice which also should continue.

Another threat which has historically caused problems for other pupfish habitats within the Death Valley system is the introduction of the exotic mosquitofish, *Gambusia affinis.* This aggressive exotic has jeopardized and almost completely displaced several pupfish populations throughout the southwest (Miller 1961, Myers 1965, Minckley and Deacon 1968). Fortunately, the elevated salinities throughout most of Cottonball Marsh and the low salinity tolerance of the mosquitofish (La Rivers 1962) would probably prevent *G. affinis* from becoming established. However, other more salt tolerant fish species like *Tilapia* sp. and *Poecilia* sp. could become introduced into various Death Valley locations. This has already occurred at the Salton Sea and appears to have caused the displacement of *C. macularius* from much of the available habitat (Black 1980). This is a perpetual problem which has no simple solution. Any exotic fish introduced into waters contiguous to the Cottonball Marsh will need to be removed as soon as possible to prevent its spread throughout the system.

STATUS

At present, the population of *C. milleri* is small but stable. The pupfish seems secure from visitor pressure under the current management practices. As long as groundwater continues to supply the Marsh the pupfish should remain secure. The fact that this is the only geographic location in the entire world where this species occurs continues to qualify *C. milleri* as a rare species on the State list.

DISCUSSION

Of the nine species of *Cyprinodon* discussed by Miller (1948) two are now extinct, three are listed as endangered, and two are listed as threatened (Deacon et al. 1979). One additional species has been described since Miller's original work - *C. milleri* - the Cottonball Marsh pupfish. This species is currently listed by the State of California as rare because the population is small, occurs within a limited range, and could become endangered if habitat alteration occurred.

The Cottonball Marsh pupfish is unique among the cyprinodonts in that it occupies the most saline, naturally occurring desert marsh in California. This salt marsh habitat has existed for a relatively short time since Lake Manly became dry. This short period of isolation from the other species of pupfish combined with their habitat diversity provides a rare opportunity to study environmental influences on species differentiation. The morphological similarity of pupfish species occurring throughout the Death Valley system reflects their recent common ancestry. This genetic closeness, however, could pose a threat to the continued survival of "pure" pupfish populations which exist today in limited habitats.

There are numerous examples of hybridization between closely related species (Schultz and Schaefer 1936, Hubbs and Katsuzo 1942, Hubbs et al. 1943, Hubbs and Miller 1943, Hubbs 1955). Any accidental or intentional introductions of these closely related pupfish species into Cottonball Marsh, for example, could result in hybridization and possible loss of *C. milleri* as a distinct species. Although Cokendopher (1980) demonstrated a low success rate for production of viable hybrid pupfish under controlled experimentation, any possible contamination should be avoided. To date this has been accomplished by two mechanisms: the first mechanism is achieved by the physical difficulty in reaching the Cottonball Marsh on foot. The terrain makes hiking into the Marsh almost impossible. The second mechanism is achieved through the NPS administration of the Marsh as if it were officially designated as a wilderness subzone.

Although the various populations of Death Valley cyprinodonts vary in their physiological characteristics, morphological features, and specific habitat requirements, there are several common habitat features which are necessary for continued survival and perpetuation. Pupfish are territorial and quite pugnacious, which requires habitat areas be large or population size is limited. Large, shallow water habitats, usually less than 10 cm deep, adjacent to deeper pool areas seem to represent an optimum for pupfish habitat. The young pupfish occupy temporary, warm, shallow water areas containing either organic substrate, emergent vegetation, or rock rubble for cover. All pupfish are opportunistic omnivores, feeding on both plant and animal matter in direct proportion to item availability. All pupfish are substrate feeders, although they may display somewhat different feeding behavior patterns. These biological, behavioral, and general habitat requirements must be maintained to ensure survival of any pupfish population, including *C. milleri.*

Continued survival of *C. milleri* is dependent upon protecting existing habitat. Future protection depends upon both the DFG and NPS maintaining a close working relationship and carrying out the specific management recommendations which follow.

RECOMMENDATIONS

The primary goal in the management of the Cottonball Marsh pupfish is to preserve the species in its natural habitat as a viable, self-sustaining population free from the modifying influences of man's activities. A secondary goal is to accommodate research on the pupfish and its habitat for the advancement of scientific knowledge and a better understanding of its management requirements. The effects of environmental stress upon *C. milleri* has already been studied, but much information is still lacking. Data on early life history, food preference, behavior (spawning and territorial), as well as other aspects of their physiological ecology are also needed.

The following actions are recommended, with the responsible agency or agencies indicated in parentheses.

1. Assist as needed congressional efforts to classify the area as a wilderness subzone (NPS).

2. Continue monitoring Cottonball Marsh daily during peak visitor use of the monument (NPS).

3. Monitor the status of water flow to the Marsh (NPS).

   a. Install staff gauges in several different pools at Cottonball Marsh, 1980-81.

   b. Consult with USGS to design a water flow monitoring program, 1980-81.

   c. Consult with USGS to identify possible future threats to surface and groundwater supplies to Cottonball Marsh, 1980-81.

4. Annually inspect the condition of the habitat and status of the Cottonball Marsh pupfish (NPS & CF&G).

5. Develop additional biological information on *C. milleri* (CF&G).

   a. Electrophoretic comparison of Death Valley cyprinodonts, 1980-81.

   b. Field study of early life history, food habits and behavior, 1981-82.

   c. Studies of physiological ecology, 1982-85.

Implementation of the above recommendations will mean that reasonable and prudent measures have been taken to guarantee continued habitat protection. However, it will not necessarily mean that *C. milleri* should no longer be classified as a rare species. The population is limited and still vulnerable to habitat modification. For this reason, the species should remain on the State list as rare. Implementation of the actions identified in this management plan; however, should provide sufficient protection for the species to keep it from becoming a threatened or endangered species in the future.

ACKNOWLEDGMENTS

Peter G. Sanchez, Park Resource Management Specialist for the Death Valley National Monument, provided a substantial amount of information on the biology of *C.* milleri. Without his input and subsequent comments on the draft, the report could not have been completed. Phil Pister has had a significant effect on the author's concern for desert fishes over the past several years and has helped formulate and develop management programs for many pupfish populations. His input was also necessary to complete the present report.

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