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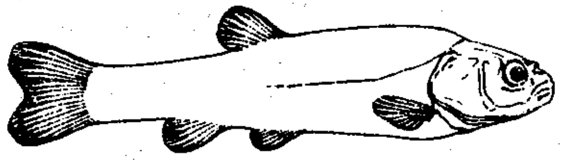
ECOLOGY OF THE NEVADAN RELICT DACE, Relictus solitarius (Hubbs and Miller)

WITH A SELECTED BIBLIOGRAPHY ON GREAT BASIN DESERT FISHES



BY
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RENO, NEVADA

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ACKNOWLEDGEMENTS

This research was sponsored by the Desert Research Institute (DRI) Project Assignment Committee, Dr. Joy H. Leland, chairman. Dr. Clifford J. Murino, DRI President, was very supportive of the work. Consultation with Dr. James E. Deacon (University of Nevada, Las Vegas) was helpful in initiating this research on relict dace.

The monumental work of Carl L. Hubbs, Robert Rush Miller and Laura C. Hubbs (1974) should be credited with providing the foundation for all subsequent research on the relict fishes of the north-central Great Basin; this is especially true of research on *Relictus solitarius*. These scientists described the taxon, determined its geographical distribution, conducted extensive work on its meristics and comparative morphology, and made notes on the ecology.

Dr. R.R. Miller (University of Michigan, Ann Arbor) kindly reviewed my proposal and sections of the manuscript for accuracy of content. Mr. David L. Galat (Colorado Cooperative Fishery Research Unit) and Dr. Thomas P. Lugaski (University of Nevada, Reno) critically read the laboratory bioassay manuscript and made helpful suggestions. Mrs. Sandra Howell-Cooper identified the macroinvertebrate organisms. DRI Water Center Analytical Laboratory conducted chemical analyses. Ms. Leslie Curral and Ms. Katrina Lasko did art work. Mrs. Rita Armstrong typed and prepared the manuscript. Mr. John Hutchins (Nevada Department of Wildlife) and Mr. Val Crisipin (Bureau of Land Management) provided important information on relict dace habitats and water quality data. Mr Eric Sprado, Butte Valley rancher, was most helpful during the field sampling and graciously allowed access to his property.

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INTRODUCTION

Distribution and Evolution

The State of Nevada comprises the heart of the Great Basin Desert. The "Great Basin" is actually composed of more than 90 basins separated from each other by more than 160 mountain ranges (Blackwelder 1948). One or both sides of these individual basins are generally bounded by great fault scarps, along which typically emanate valley-edge or bottom springs; these micro-aquatic habitats often incredibly contain remnant fish life of the basin (Hubbs et al. 1974). In contrast, the more permanent-appearing canyon and mountainside streams seldom contain native fish, presumably due to the devastating effects of the rare occurrence of torrential rainfall and resultant flash floods.

Much of today's unique desert fish fauna was derived from a primarily lacustrine ancestral stock inhabiting the Pleistocene lakes of which Lakes Lahontan and Bonneville inundated about one-fifth of the entire area of the Great Basin. Relict dace *(Relictus solitarius)* evolved during the past 1.5 to 2.0 million years in the contiguous drainage basins of Pluvial Lakes Franklin, Gale, Waring, and Steptoe just south of the conjoining parts of the Lahontan and Bonneville basins (Hubbs et al. 1974; R.R. Miller, University of Michigan, personal communication). As these Pleistocene Lakes desiccated over the last 10,000 years, the relict dace was the only genus and species of fish to survive in the remnant springs of contemporary Ruby, Butte, Goshute and Steptoe Valleys, which comprise some 14,682 km^2 in northeastern Nevada. The species also occurs in Spring Valley where it is believed to be an introduction. Most of the local differentiation and endemism among the fishes of the isolated desert waters dates from the end of the glacial period (Hubbs and Miller 1948).

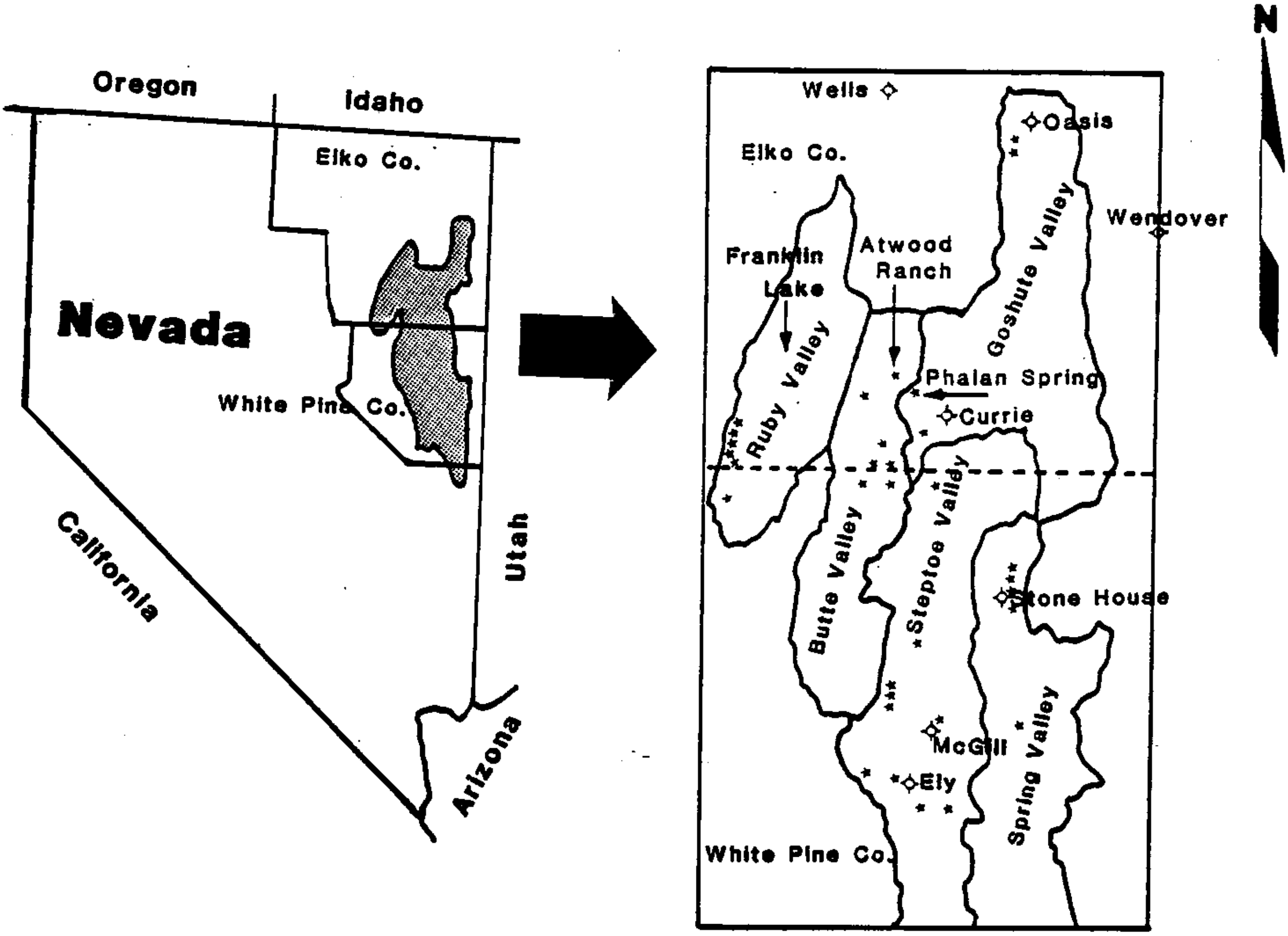
Study Sites

The geographical distribution of relict dace was documented by Hubbs et al. (1974) during field collections from 1934 to 1971 *(Figure 1)*. Few additional habitats have been found; these include Franklin Lake and Alkali Pond in the Ruby Valley, and the recent introduction of the species into Shoshone Ponds in Spring Valley. Hardy (1979) lists 19 habitats in which relict dace are known to exist; however, some of these locations are questionable and others which were formerly extensive spring, creek, and slough complexes are now greatly reduced in size. Table 1 is a compilation of all known habitats of relict dace, past and present.

During this study I visited most of the habitats in Ruby, Butte, Goshute and Steptoe Valleys. Samples from Franklin Lake, Atwood Ranch Springs, and Phalan Springs were used in laboratory bioassays.

Status

It seems unbelievable that the relict dace could have persisted continuously for thousands of years in the fragile environments of small desert springs, creeks, and marshes; in fact it is probable that much extinction of fish species occurred as late Pleistocene desiccation advanced (R.R. Miller, personal communication). Obviously man's demand for water in these arid valleys has the potential to heavily impact the desert fish of Nevada. Today most of the endemic fish species of Nevada are in danger of extinction. Over 30 of Nevada's fish species are listed as being endangered, threatened, or of special concern; and most of these occur only in Nevada (Deacon et al. 1979, Miller 1979).



▨ Geographical distribution of relict dace

← Location of habitats where bioassay test fish were collected

* Relict dace habitats documented by Hubbs et al. (1974)

FIGURE 1. Areal distribution of relict dace in five valleys in northeastern Nevada.

TABLE 1. Specific locations of relict dace habitats, northeastern Nevada.

Pluvial Lake/ Valley	Habitat	Alternate Name	Collected by Hubbs et al. (1974) (number)	Location (Township Range Section)	Currently known to exist	Extirpation	
						Hubbs et al. (1974)	Currently Probable
Lake Franklin ***Ruby Valley***							
	Ruby Lake	(marshes including 10 springs on west side)	-	T27N,R57-58E		X	X
	North Sump	-	-	T27N,R58E,S5 (NW ¼)	X^{1}		
	CCC Dike	-	-	T27N,R58E,S22 (N edge)	X^{1}		
	Minnie Sp.	-	-	T27N,R58E,S10	X^{1}		
	Borrow Pit	-	1	T27N,R58E,S14			
	Pothole Sp.	-	2	T27N,R58E,S19			
	Unnamed Sp.	-	3	T27N,R58E,S18/19			
	Slough below Cave Cr.	-	4	T27N,R58E			
	Unnamed Sp.	(near western border of refuge)	5	T27N,R58E	X^{2}		
	Unnamed Sp.	(near southern border of refuge)	6	T26N,R57-58E			
	Franklin Lake	-	-	T29N,R58E	$X^{2,4}$	(Lake dry in 1934)	
	Narcisse Sps.	-	-	T25N,R57E,S2	$X^{2,4}$		
	Unnamed Sp.	(N.E. Sp?)	-	T28N,R58E	$X^{2,3,4}$		
	Alkali Pond	-	-	T25N,R57E	$X^{3,4}$		
Butte Valley							
	Atwood Ranch	(Kirkpatrick R., Don Phelan R., Sprado R.)	7-9	T29N,R62E	$X^{2,4}$		
	Trib. Butte Cr.	(Quilici R. Delker Spring)	10	T28N,R61E,S2	$X^{2,4}$		
	Head Odgers Cr.	-	11	T27N,R62E,S28-29	X		
	Odgers Cr.	(Taylor R.?)	-	T28N,R61E,S2	X^{2}		
Lake Gale ***Butte Valley***							
	Stratton Ranch Sp.	(Parris R.)	12,14	T26N,R62E,S15			X^{2}
	Wrights Spring	(Parris R.)	13	T26N,R62E,S16			X^{2}
	Owens Ranch	(Spring Creek?)	15	T26N,R62E,S17	X^{2}		
	Unnamed Sps.	-	-	T28N,R61E,S2	X^{2}		
Lake Waring ***Goshute Valley***							
	Johnson Ranch Sp.	(Big Springs R.)	16,17	T26N,R66E,S29			$X^{2,4}$
	Phalan Cr.	(Twin Springs)	18	T29N,R63E,SE¼	$X^{2,4}$		
	S. of Currie	(Currie Pond)	19	T27-28N,R64E			X^{4}
Lake Steptoe ***Steptoe Valley***							
	Cardano Ranch Sp.	-	20	T25N,R64E,S5	$X^{2,4}$		
	Warms Sps. Station	(Monte Neva Slough)	21	T21N,R63E,S25			$X^{2,4}$
	Steptoe Ranch Sps.	(Campbell R.)	22,23	T19N,R63E,S5	$X^{2,4}$		
	Steptoe Ranch Sps. Slough	(Duck Ck. Slough)	-	T19N,R63E		X	
	Grass Sps.	(Lusetti R.)	24	T19N,R63E,S20	X^{4} (One spring pond)	X (Extirpated from largest spring by exotic fish)	$X^{2,5}$ (Extirpation in at least 20 of 25 springs)
	Dairy Ranch Sprs.	(Below McGill swimming pool)	25	T18N,R64E,S20	X^{2} (Only one specimen)		X^{2} (Extirpated at four locations)
	Georgetown Ranch	(Tributary of Murray Cr)	26	T16N,R63E		X (Extirpated from largest spring when cemented in)	
	Steptoe Cr.	(S. of Ely)	-	T16N,R63E			
	Ruth Pond	(W. of Ruth)	-	T16N,R62E	$X^{2,6}$		
	3 C Ranch	(Fish Pond Sps)	28,29	T15N,R64E,S5/8			
	Murphy Ranch	(Dolan R.)	-	T25N,R64E		X (Extirpated by exotic introduction)	
	Lackawana Sp.	-	-	T16N,R63E		X (Extirpated by bathhouse)	
Lake Spring ***Spring Valley***							
	Spring Valley Cr.	-	30,31	T23N,R66E,S31	$X^{2,6}$		
	Stone House	-	32,33	T22N,R66E,S17	$X^{2,6}$		
	Keegan Ranch	-	34	T18N,R66E,S12	$X^{2,6}$		
	Shoshone Ponds	-	-	T13N,R65E	$X^{2,5}$ (recently introduced)		

[1] *Documented by D.E. Lewis in 1967, reported by Hubbs et al. (1974), probably not currently in existence.*

[2] *Documented by Hardy (1979).*

[3] *Documented by Ruby Lake National Wildlife Refuge Personnel during 1979-1980.*

[4] *Documented by this study.*

[5] *Documented by Nevada Department of Wildlife personnel (1977-78).*

[6] *Introduced populations.*

Relict dace was once the most abundant of the four fish species native to the north-central Great Basin. Hubbs et al. (1974) recorded numerous instances of the extirpation of the relict dace from their natural habitats; the most notable example being the management practices of the Ruby Marshes which lead to the elimination of the species from all but the most isolated and marginal habitats. Perhaps the most detrimental impact has been competition and predation by exotic fish species; primarily; largemouth bass *(Micropterus salmoides)*, rainbow trout *(Salmo gairdneri)*, Sacramento perch *(Archoplites interruptus)*, carp *(Cyprinus carpio)*, goldfish *(Carrasius auratus)* and Utah chub *(Gila atraria)*.

To date, the species continues to lose populations and habitat. Nevada Department of Wildlife found relict dace in only five of 25 known habitats in the Grass Spring complex in 1977-78 (Steptoe Valley); Hardy (1979) recorded the apparent extirpation of the species at the Stratton Ranch Springs and Wrights springs (Butte Valley). Although I was not permitted to sample, I observed no fish at the Johnson (Big Springs) Ranch. I conclude this unique population in northern Goshute Valley has probably been killed off. All of the aforementioned springs were modified (via concreting, damming, plumbing, etc.) into stock ponds, domestic water supply, and/or irrigation systems. The proposed M-X missle system could also severely impact relict dace (Hardy 1979); if the M-X operating base were located at Ely and the proposed White Pine Power Project were located at Ely and the proposed White Pine Power Project were constructed in Steptoe or White River Valleys, there is potential for cumulative effects of groundwater withdrawal on at least the southern Steptoe Valley relict dace populations (USADF 1980, M-X Draft EIS). In summary, predation and competition by exotic fish species, modification of natural springs, and groundwater mining have all caused detrimental impacts on the species.

The relict dace is listed as "of special concern" by the Endangered Species Committee of the American Fisheries Society (Deacon et al. 1979). However, it has recently been taken off the State of Nevada's protected list.

Importance

The economic value of relict dace, in the conventional sense, is minimal. Hubbs et al. (1974) list past uses of the fish, including: human food (like sardines), live bait for gamefish, feed for raising bullfrogs, coyote trapping scent, and mosquito control. Under natural conditions, relict dace are poorly suited as forage for game fish. The (largely degenerative) adaptations of the species for existence in small desert springs makes it unfit in the face of exotic competitors and predators; this has been documented in numerous instances, the most blatant being its extirpation from the relatively vast area of the Ruby Marshes. Biologists have previously attempted to find other uses of endemic cyprinids (e.g. aquarium fish and experimental animals) in order to attach monetary value and thus justify their existence; however, the most compelling argument is their intrinsic value as a unique species which contributes to the diversity of life.

The interplay of economics with perceived value in society has caused the numerous ecological problems leading to extinction of species; however, based on the conclusions of various disciplines of philosphers concerning the relationship between man and the environment, society has begun to slow the extinction process via accumulation of knowledge and concomitant legislation (Deacon 1979). During the past two decades it has been brought to the public attention that the endemic fishes of the Great Basin represent a unique scientific resource in terms of the diversity of nature, natural history, environmental adaptation, and the evolution of species. Over eons of time this ecosystem has become a natural laboratory of genetic selection which rivals the faunal adaptations of the Galapágos Islands which inspired Darwin. Hubbs et al. (1974) characterize the Great Basin as "..., a vast arena wherein there has long been an active interplay between the processes of faunal establishment and extinctions, habitat disruption, and the isolation and differentiation of the remnant fish population." However, the scientific value of the Great Basin as a laboratory of natural selection is currently being impaired since many components of this resource are now in danger of extinction due to artificially accelerated degradation of habitat, including introductions of exotic fish.

Literature Review

The published literature on relict dace is sparce, consisting of: Hubbs and Miller (1948, 1970, 1972), distribution and description; La Rivers (1962), brief mention; Hubbs et al. (1974), comprehensive; Smith (1978), distribution; Deacon et al. (1979), status list; Hardy (1979), population inventory; Lugaski (1980), chemotaxonomy; and USDAF (1980), environmental impact. Unpublished reports on relict dace include population inventories conducted by the Nevada Department of Wildlife in conjunction with the Bureau of Land Management (1980).

Most of the knowledge on relict dace (especially distribution and morphology) is contained in the work by Hubbs et al. (1974). However, prior to the present study very little was known on the physical and chemical characteristics of relict dace habitats, habitat requirements of the species, and ecological relationships.

Objectives

The purpose of this research was;

1) To compile a comprehensive bibliograhy on desert fishes in the Great Basin, particulary Nevada.

2) To quantify physical and chemical characteristics of present day relict dace habitats.

3) To quantify habitat requirements of relict dace, specifically salinity and temperature.

4) To gather information on life history and ecological relationships.

5) To integrate the previous knowledge with the data collected in the form of a Desert Research Institute technical report.

PROCEDURES

Field Collections

Four sampling trips were made during September, October and December 1980, and February 1981. During this period over 20 relict dace habitats were sampled in Ruby, Butte, Steptoe, and Goshute Valleys *(Table 2)*. Fish were captured with a backpack electroshocker, dip nets, and minnow traps; the latter two methods were primarily used.

Live fish to be used for behavioral observations and laboratory experimentation were transferred in their natural water in ≃130-liter plastic containers. The water was continuously aerated, and monitored for dissolved oxygen (DO) and temperature during transport. Specimens to be subsequently analyzed for diet were intraperitoneally injected with 10% formalin and placed in a labelled plastic container of 10% formalin. In the laboratory the stomach contents were processed, preserved in 70% ethyl alcohol and enumerated.

Selected habitats were qualitatively sampled for benthic macroinvertebrates. Substrate was scooped up and washed through a Ponar screen (mesh size 520 microns). The sample was labelled and preserved in 10% formalin. In the laboratory the sample was processed for organisms which were subsequently preserved in 70% ethyl alcohol and enumerated to family or genus.

Temperature of each habitat was measured *in situ* with a mercury bulb thermometer; dissolved oxygen was measured with a YSI Model 57B oxygen meter. In selected habitats, temperature, DO, pH and conductivity were measured with a calibrated Hydrolab Surveyor Model 6 D. A 19-liter plastic bucket was used to take a sample from the habitat and the Hydrolab probe was immediately inserted.

TABLE 2. Relict dace habitats sampled, September 1980 - February 1981.

		Sample				
Date	**Valley/Habitat**	**Fish**	**Observation (temperature)**	**Hydrolab**	**Mineral**	**Nutrient**
09/30/81	**Ruby**					
	Narcisse Sp.	X^1	X			
	North-east Sp.	X^1	X			
	Franklin Lake	X^1	X			
	Butte					
	Atwood R. Sp.	X^2	X			
10/08/80	**Steptoe**					
	Cordano R. Sp.	X^2	X			
	Dairy Fields Sp.		X			
	Steptoe R. Sp.	X^2	X			
	Bassett Lake		X			
12/02/80	**Ruby**					
	Narcisse Sp. Pond		X	X		
	Alkali Pond		X	X	X	X
	N. Narcisse Sp.		X	X	X	X
	N. Narcisse Sp. #2		X	X		
	Franklin Lake		X	X	X	X
	Steptoe					
	Grass Sp.	X^2	X	X	X	X
	Steptoe R. Sp. #1	X^2	X	X		
	Steptoe R. Sp. #2	X^2	X	X	X	X
	Steptoe R. Pond	X^2	X	X	X	X
	Cordano R. Sp. Head	X^2	X	X		X
	Cordano R. Sp. Creek	X^2	X	X		
	Bassett Lake		X	X		
	Butte					
	Atwood R. Pond	X^3	X	X	X	X
	Atwood R. Channel	X^3	X	X		
	Quilici Sp.	X^2	X	X	X	X
	Taylor Sp. (Odgers)	X^2	X	X	X	X
	Paris (Stratton) R.		X	X		X
02/25/81	**Goshute**					
	Big Springs (Johnson)R.Sp.		X			
	Phalan (Twin) Sp.	X^3	X	X		
	Atwood R. Pond	X^3	X	X		
	Curry Pond		X			

[1] *Backpack electroshocker*

[2] *Dip nets*

[3] *Minnow traps*

Gross mineral and nutrient (orthophosphorus and nitrate) analyses were conducted on selected habitats. Water samples for the standard mineral analyses were collected in 3.8-liter plastic containers and immediately placed on ice in the dark. Nutrient samples were collected in 250 mℓ plastic containers and immediately frozen on dry ice. The Desert Research Institute Water Center Analytical laboratory conducted the water quality analyses according to standard methods (APHA et al. 1975, EPA 1974).

Laboratory

Temperature salinity bioassays were conducted on relict dace from November 1980 - March 1981. Test fish were transported from their natural habitats in Ruby, Butte, and Goshute Valleys *(Figure 1)* to the Desert Research Institute (DRI), Bioresources Center Laboratory in Reno. Upon arrival at DRI the fish were maintained in 425-liter holding tanks a minimum of four days for observations of handling stress. During this time the fish were acclimated at 18-20 C in de-chlorinated Truckee River water prior to testing.

Relict dace from three different sources (Franklin Lake, Atwood Ranch, and Phalan Spring) were tested for 96 hours over a temperature range of 29.0 to 34.3 C. Two replicates of five fish each were tested in 19-liter aquaria for each treatment. The test aquaria were placed in a thermostatically controlled water bath to maintain a constant temperature (±0.1 C). Five control fish were placed in de-chlorinated Truckee River water in a 19-liter aquarium at room temperature (approximately 20 C) for each treatment. During all tests, no mortality occurred in any control.

Test fish were not fed 24 hours prior to the bioassay nor during the tests. Dissolved oxygen and pH were measured at least once and usually three times daily. The aquaria were continuously aerated, and mean DO values always exceeded 6 mg/liter. Temperature was measured at least three times daily in each aquarium with a calibrated digital thermometer.

Range finding tests were conducted to determine the TDS-alkalinity tolerance of relict dace. Concentrated Pyramid Lake water (2X, 3X, 4X) was used to achieve elevated salinity levels *(Table 3)*. Fish were derived from two sources in order to test for differences by population, i.e., Atwood Ranch Spring and Phalan Spring. Procedures similar to those of the thermal bioassays were used: five fish/test in 19-liter continuously aerated aquaria with selected environmental parameters monitored. Temperature was held constant (21.4-22.3 C) via the thermal water batch. Data were interpreted in terms of resistance time as well as mortality.

Another series of tests were performed to evaluate salinity-temperature interactions, utilizing only the Atwood Ranch Spring population. Pyramid Lake water (1X), and ½ Pyramid - ½ distilled water were utilized as the test media for normal (≃21-22 C) and elevated (≃30 C) temperatures. For all salinity tests, Truckee River water (low TDS) was used as controls. Electrical conductivity and alkalinity determinations for each treatment were determined by the DRI water chemistry lab using standard analytical procedures (APHA 1975). TDS was determined by summation of all measured constituents.

The total and mean weight of each group of five test fish were determined (in water) to the nearest 0.1 gram prior to being placed into the test aquarium. Dead fish were immediately removed and preserved in 10% formalin; time of each death was recorded. The criteria for death were no opercular movements and no response to touch. Statistical analyses were conducted utilizing programs from SPSS (Nie et al. 1975).

TABLE 3. Ionic composition of test media for TDS-alkalinity bioassays.

Test media	TDS* (mg/ℓ)	Total alkalinity (mg/ℓ)	Specific conductance (μmhos/cm @ 25 C)	pH
Truckee River	157	78	187	7.5
½ Pyramid Lake ½ Distilled	2,845	639	4,730	9.2
1X Pyramid Lake	5,652	1,262	8,560	9.2
2X Pyramid Lake	11,043	2,580	16,900	9.2
3X Pyramid Lake	15,759	3,670	22,900	9.2
4X Pyramid Lake	20,475	4,620	28,200	9.1

*Summation of all constituents.

TAXONOMY

All of the morphological work on relict dace has been done by Drs. C.L. Hubbs and R.R. Miller; therefore, most of the information presented in this section is summarized from their publications. Dr. T. Uyeno conducted a chromosomal analysis of relict dace and processed the karyotype. Electrophoresis of relict dace tissues has recently been conducted by Lugaski (1980).

Derivation of name

Relictus solitarius (Hubbs and Miller)

Relictus - is a Latin term meaning to leave behind (past participle of reliquo) or forsaking or abandoning (noun).

solitarius - is a Latin term defined as alone, by itself, lonely, solitary.

The name refers to the fact that the fish is the lone native inhabitant of Pleistocene Lakes Franklin, Gale, Waring and Steptoe; it was probably relict in only one of the main drainage complexes, i.e. Franklin or Waring (Hubbs et al. 1974).

Description

The following are the original descriptions for the monotypic genus *Relictus*, and species *R. solitarius* by Hubbs and Miller (1972, p. 101-102). The type specimens are deposited in the University of Michigan Museum of Zoology (UMMZ).

Relictus n. gen.

Type species.—Relictus solitarius.

A cyprinid of moderate size (larger than *Rhinichthys)*, with some distinctive osteological characters: dorsal crest of maxilla greatly expanded upward and backward; cleithrum slender; supraethmoid elongate, slender medially but notably expanded laterally at front (resembling that of *Rhinichthys);* urohyal long and narrow. Vertebrae 35-39. Pharyngeal arch moderately strong and heavy, but rather thin and somewhat lacy on the strongly expanded median section; not strongly elevated at the posterior end of the tooth row; without a flattened shelf on which a second tooth row might develop; teeth 4—4 (rarely 5—4 or 4—3). Gill-rakers small and few (7-12, usually 8-11, on first arch). Mouth oblique and terminal, completely lacking horny cutting edges; no frenum or barbel. Lateral line obsolescent, rarely extending to below origin of dorsal fin, commonly disrupted; total pores 3-29. Supratemporal canal seldom complete (only 4 of 76 specimens have the commissure closed), with usually 3 or 4 (0-5) pores in each lateral segment; preoperculomandibular pores 11-19; mandibular pores 3-8. Scales rather small (50-70 transverse rows), poorly imbricated and markedly irregular; each usually vertically oval but sometimes becoming rectangular with age; with numerous radii on all fields (much as in *Rhinichthys* and some other Western genera). Fins small and strongly rounded; the pelvic especially and uniquely paddlelike; dorsal and pelvic both displaced backward, and both beginning at approximately the same vertical (as in the subgenus *Siphateles* of the genus *Gila* and in many species of the typical subgenus *Gila*); dorsal and pelvic rays typically 8, anal 7. Nuptial tubercles form a highly distinctive pattern on head; the largest uniserially line the infraorbital sensory canal and suborbital margin; large uniserial caducous cones (much stronger than in *Gila*) line the upper edge of the first pectoral ray; smaller cones, also strictly uniserial (not forking once as they do in *Rhinichthys*) occur along one to several following rays; in high males some tubercles develop along outer pelvic rays and along first anal rays. Head and body turgid. Coloration much as in *Siphateles*, rather even, and often with large melanophores on lower side; lacking the two lateral bands, the head stripe, the paired light spots at caudal

> base, and other features characteristic of *Rhinichthys*. Intestine forming a single, simple, compressed-S loop, as in *Rhinichthys* and many other American cyprinids. Karyotype distinguished by a relatively large number (2 large and 8 small) of acrocentric chromosomes but many (12) metacentrics; remaining 28 are subtelocentric and submetocentric (total 50 as in other American cyprinids examined).
>
> ### Relictus solitarius n. sp.
>
> *Holotype.*— UMMZ 186904, a nuptial male 60.3 mm in standard length, from upper, hillside spring on Kirkpatrick Ranch (earlier called "Atwood Ranch," later called "Don Phalan Ranch") on east side of Butte Valley north of the narrows, in east part of T.29 N., R.62 E., Elko County, Nevada, 21 km northwest of Currie; collected by the Hubbs family June 27, 1942 (collection H42-47).
>
> The characters of the species are essentially those of the genus. Counts for the holotype and the paratypes (UMMZ 141518) from the same collection follow. Rays: dorsal 7-8 (mean 7.40), anal 6-7 (6.95), caudal 18-21 (19.17), pectoral 13-16 (14.17), pelvic 7-9 (7.95). Vertebrae: 35-37 (36.07). Scale-row counts: lateral-line 50-57 (54.6), predorsal 30-33 (31.4), dorsal to anal origins 21-23 (22.4), around body 55-58 (55.8), around peduncle 30-31 (30.2). Pores: lateral-line 13-26 (18.4), supratemporal 2-4 (3.0), mandibular 4-7 (5.33). Gill-rakers 7-11 (8.90). Measurements of holotype in thousandths of standard length: predorsal length 579, anal origin to caudal base 318, body depth 295, caudal-peduncle depth 158, head length 282, head depth 207, head width 170, snout length 76, orbit length 59, upper-jaw length 82, mandible length 102, interorbital width 88, suborbital width 41, depressed-dorsal length 223, caudal length 238, pectoral length 208, pelvic length 160.

Specimens of relict dace I collected from Atwood Ranch (Butte Valley) and Franklin Lake (Ruby Valley) are presented in Figure 2. The holotype described by Hubbs and Miller (1972) was from the Atwood Ranch population; the Ruby Valley population is considered to be the most highly differientated form.

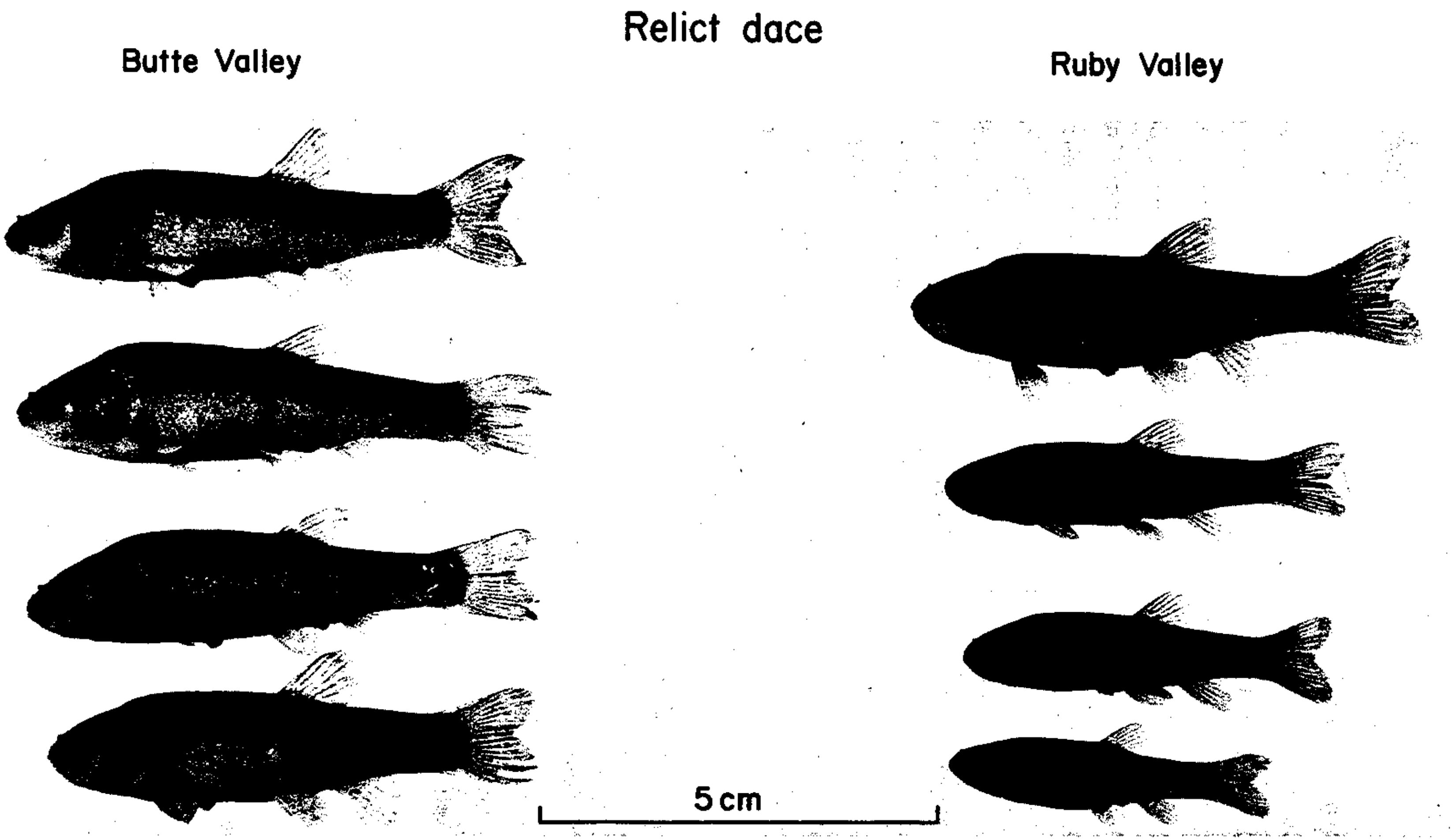


Figure 2. Relict dace collected from the Atwood Ranch Spring in Butte Valley, and Franklin Lake in Ruby Valley, October 1980.

Morphology

The morphological adaptations of relict dace are probably related to their isolation in small spring systems and subsequent lack of competition and predation by other fish species. These factors have also contributed to variability of their characteristics. Relict dace provides an excellent example of the modification, in part degenerative, which characterizes cyprinids confined to isolated springs in the Great Basin (Hubbs et al. 1974). The relict dace has a non-streamlined form adapted to midwater swimming in a lotic environment. The small, weak, rounded fins also correspond to limited locomotion. The chubby body has nearly symetrically curved dorsal and ventral contours, with a thick caudal peduncle and a relatively large, rounded, terminal mouth ***(Figure 3)***. Scales are irregular and deeply imbedded. The lateral line sensing organ is greatly reduced. Primary meristics are quantified in Table 4, and proportional morphology is presented in Table 5. (After Hubbs et al. 1974).

Extreme modification of the normal form occurs in oversized fish. *Relictus solitarius* is normally 60-100 mm in standard length; the northern Goshute Valley (Johnson Ranch) population is the only one Hubbs et al. (1974) found to exhibit individuals greater than 100 mm. These specimens, which represented less than 1% of the sample, looked abnormal and were regarded as superannuated. The maximum size recorded for the species is 114 mm. At the other extreme, the Ruby Valley populations are thought to represent a dwarfed form. All of the Ruby Valley specimens collected by Hubbs et al. (1974) were less than 60 mm in length. Ironically, both of these unique forms are in danger of extirpation.

Coloration of relict dace is extremely variable; this is another unique feature of the species which is related to reduced selection pressure. Hubbs et al. (1974) recorded the following life-colors: General tone is dusky, strongly speckled with brown

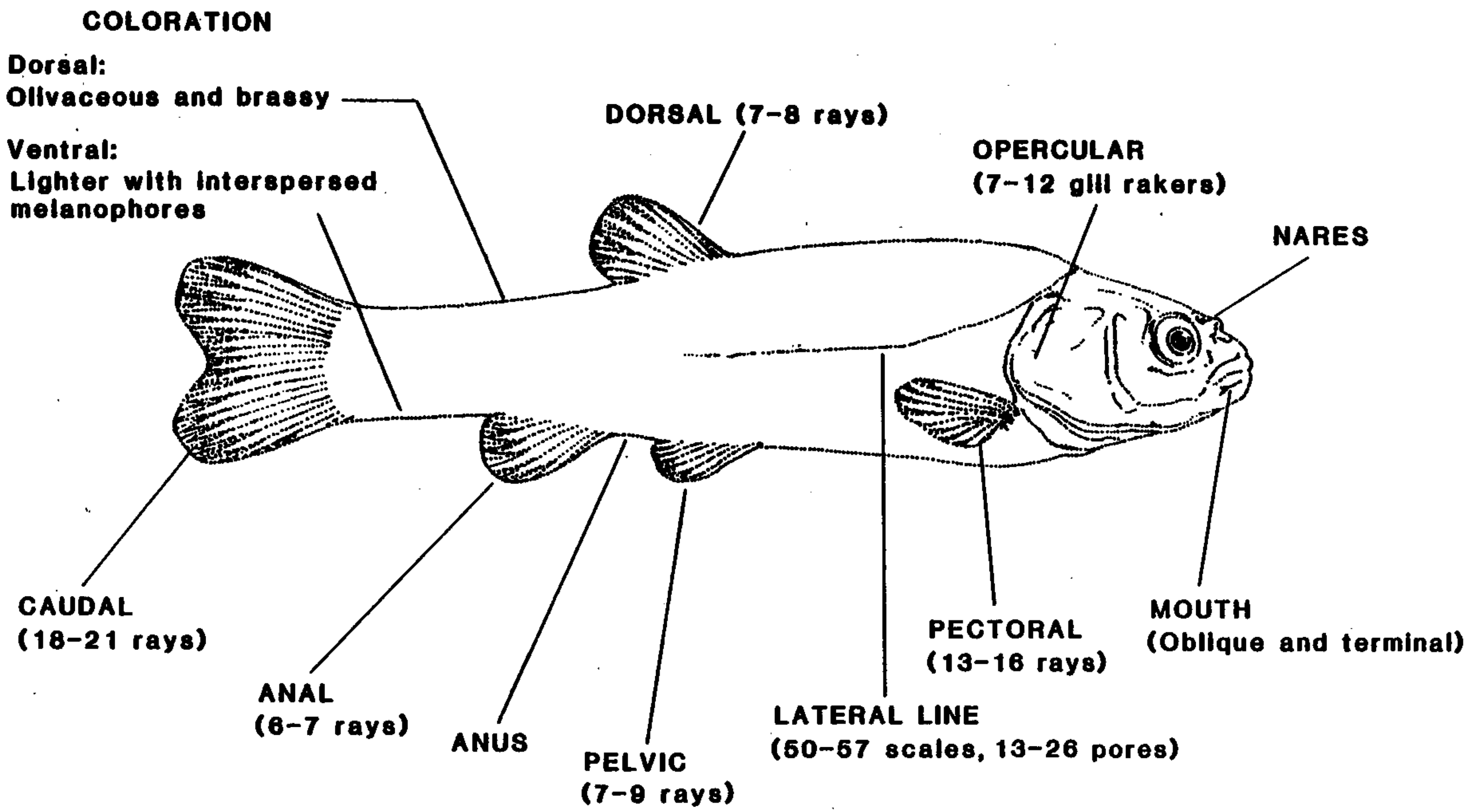


Figure 3. Morphological characteristics of relict dace. Meristic data are derived from the holotype description (Hubbs and Miller 1972).

TABLE 4. Meristics of relict dace from various populations (After Hubbs et al. 1974, p. 222-224).

Taxonomic Character	Sample Size	NUMBER		
		Range	Mode	Mean
Fin rays				
Dorsal	132	7-10	8	7.96
Pectoral[1, 2]	230	9-16	14	13.87
Pelvic[2]	468	5-9	8	7.98
Anal	132	6-8	7	6.96
Caudal	104	16-21	19	18.95
Vertebrae[1]	139	35-39	36	36.51
Gill rakers[1]	115	7-12	9	9.35
Scales in row				
Lateral line	75	50-70	-	59.1
Predorsal	65	27-39	-	32.8
Dorsal-anal	65	20-28	-	23.3
Around body	65	52-66	-	58.7
Around peduncle	65	28-34	-	30.6
Pores				
Lateral line[2]	65	3-29	-	16.0
Supratemporal[2]	65	2-5	-	3.2
Mandibular	158	3-8	5	5.27

[1] *Mode varies by population*

[2] *Counts made on both sides*

TABLE 5. Proportional measurements, in permillage of standard length, for male (24-66 mm) and female (30-114 mm) relict dace (After Hubbs et al. 1974, p. 212-213).

Characteristic	MALES (n=138)		FEMALES (n=204)	
	range	mean	range	mean
Predorsal length	534-634	585	532-688	601
Anal origin to caudal base	278-371	324	249-345	301
Body depth	241-328	282	243-347	287
Caudal-peduncle depth	116-173	143	111-182	139
Head length	255-327	296	245-341	299
Head depth	191-241	212	175-233	209
Snout length	64-92	80	65-104	85
Orbit length	52-93	70	43-90	61
Upper jaw length	65-102	83	71-112	87
Mandible length	87-126	108	88-130	109
Interorbital width	80-114	97	76-120	99
Suborbital width	32-54	41	33-59	44
Depressed dorsal fin	204-281	241	159-246	204
Caudal fin length	209-284	245	178-279	229
Pectoral fin length	164-264	215	143-213	177
Pelvic fin length	130-194	163	106-175	135

or in some locations, with moss green. Bright blue reflections are generally apparent, sometimes with gilt or a tinge of violet. The lower parts are lighter, often silvery or white with a blue tinge. Sometimes the dusky dorsal color or a yellowish color extends to the ventral surface. A narrow deep-lying dorsolateral stripe of pearly or golden color occurs between the dorsal and ventral surfaces. The midsides are often largely silvery with reflections of brassy or violet. The lower fins are often yellowish or lemon, occassionally bright golden. They reported much variation on an individual and geographic basis. One specimen was so golden it appeared to be a mutant; I also captured a relict dace which was totally golden in color.

Relict dace exhibit sexual dimorphisim of several characteristics. Females are larger than males; of 1,370 specimens the maximum length of females was 114 mm compared to 66 mm for males (Hubbs et al. 1974). The mean size of mature males in five collections was 68 to 86% of that of females. Males exhibit longer, wider fins with thicker rays. Breeding males exhibit more extensive adult coloration and at a smaller size. Males develop a characteristic pattern of nuptial tubercles on their head and fins, none are found on the body. The modification of the head in oversized females is extreme. The sex ratio of mature relict dace collected by Hubbs et al. (1974) was highly variable ranging from 29 to 99 males per female.

Evolution and Genetics

Evidence on osteological traits, morphology pigmentation, karotype, geographical, and paleohydrographic considerations lead Hubbs et al. (1974) to conclude the *Relictus* is an old relict (likely pre-Pliocene) that was derived from an ancestoral line from which *Gila* and *Rhinichthys* were also derived. Relationships among the three genera are presented in Table 6. Among living species of *Gila*, *G. atraria* and *G. bicolor* are probably close relatives.

TABLE 6. Comparisons between *Relictus* and related genera (After Hubbs et al. 1974, p 194).

Character	*Relictus*	*Gila*	*Rhinichthys*
Supraethmoid	Like *Rhinichthys*	Short, broad	Long, narrow
Dentition (normal)	0,4-4,4	Variable, 1 or 2 rows	1,4-4,1 or 2,4-4,2
Barbel	None	None	Present[1]
Frenum	None	None	Present or not[2]
Scales in lateral line	50-70	40-90	35-90
Scale radii	On all fields	Basal radii usually lacking	On all fields[3]
Anal rays	Typically 7	6-11	Typically 7
Gill-rakers	7-12	5-40	5-10, usually 6-8
Vertebrae	35-39, usually 36 or 37	38-49	35-41
Preoperculomandibular pores	11-19	13-30	8-13
Supratemporal canal	Incomplete	Complete or incomplete	Complete or incomplete
Origin of dorsal fin	Slightly before to slightly behind pelvics	Over or behind pelvics	Behind pelvic insertion (except in *R. falcatus*)
Development of lateral line	Incomplete; rarely as far as D. origin	Complete (rarely disrupted)	Variable
Peritoneum	Silvery, with brown puncticulations	Variable	Variable; dark brown or silvery (with puncticulations)
Intestine	Like *Rhinichthys*	Single loop with bend	Single loop
Type ("Group of Kafuku, 1958)	1	2 (with variations)	1

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[1] Barbel lacking on one or both sides in some populations, particularly in isolated waters.

[2] Frenum developed in subgenus *Rhinichthys;* lacking in subgenus *Apocope,* except variably developed in Colorado River system; lacking in *R. falcatus.*

[3] Anterior radii weak or obsolete basally in *R. falcatus* (perhaps generically separable).

The diploid number of 50 chromosomes of relict dace is characteristic of all American cyprinids; however the karotype of *Relictus* is very distinctive having a relatively large number of acrocentric chromosomes (Uyeno cited in Hubbs et al. 1974). The karyotype of *Relictus* is probably closest to that of *G. bicolor*.

Lugaski (1980) found via electrophoretic analysis that *Relictus* was genetically distinct from other Great Basin genera, i.e. *Gila, Rhinichltys, Moapa,* and *Eremichthys*. However, the migration rates and non-binomial distribution of the LDH isozyme, and the genetic similarity coefficient illustrated a relationship between, *Relictus* and *G. alvordensis*. Lugaski (1980) interprets this to mean that *G. alvordensis* and *R. solitarius* are related by a common cyprinid ancestor in the distant past (pre-Pliocene) that also produced the non-binomial distribution of the LDH isozyme. Since all the other chub and dace populations examined in the Great Basin exhibit a normal binomial distribution of LDH isoenzyme it is apparent that *R. solitarius* and *G. alvordensis* have been isolated from other cyprinids for a long time, probably since the Pliocene or earlier (Lugaski 1980).

HABITAT- ENVIRONMENTAL CHARACTERISTICS

In Situ Water Quality

Temperature, dissolved oxygen (DO), pH, and conductivity were measured in 17 relict dace habitats during December, 1980 *(Table 7)*. During this cold season, variation in the thermal characteristics of the different habitats were apparent. In general, lakes and impoundments exhibited the coldest temperatures (2-7 C), non-thermal springs were intermediate (8-12 C), and geothermal springs and ponds were in the 15-21 C range. Likewise the shallow standing bodies have the most seasonal variation, non-thermal springs are somewhat moderated, and geothermal springs exhibit a nearly uniform temperature on a diel and seasonal basis.

The maximum water temperatures for relict dace habitats probably occur in shallow ponds during mid-summer, e.g., Franklin Lake. However, the maximum temperature recorded in a relict dace habitat by Hubbs et al. (1974) during the hot season was only 25 C. Five habitats measured by the BLM (Water Analysis and Consulting Inc. 1980) exhibited very little seasonal variation in water temperature; Odgers Creek showed the most variation, i.e., 12-20 C from April - September, 1980. I measured the diel changes in water quality at one of the warmest thermal habitats, Phalan Spring, during February 1981 when air temperature varied from 7.5 C to -9.0 C (*Table 8*). At the head of the spring the temperature changed only 0.75 C (19.50 - 20.25). In the outflow some 125 m downstream, there was a 2.0 C variation (18.0 - 20.0 C).

D.O. was generally at concentrations which would not be detrimental to fish, >6.0 mg/ℓ. In the habitats surveyed during the day, the D.O. levels were inversely associated with the water temperature, illustrating

TABLE 7. Water chemistry data collected at relict dace habitats with a Hydrolab water analyser from 12-03-80 to 12-05-80.

Valley	Site	Temperature (°C)	Dissolved Oxygen (mg/ℓ)	pH	Conductivity (µmhos/cm^2)
Ruby	Narcissus Pond	5.0	13.0	7.50	320
	Alkali Pond	2.0	14.0	8.00	1000
	N. Narcissus Spring	8.5	12.0	7.10	350
	N. Narcissus Spring 2	10.0	11.6	7.20	330
	Franklin Lake	3.5	14.6	8.00	690
Steptoe	Basset Lake	2.0	13.4	8.10	1000
	Grass Spring	11.5	11.6	6.90	405
	Steptoe Ranch Springs *(downstream)*	21.0	7.2	6.20	405
	Steptoe Ranch *(large spring)*	21.0	7.6	6.25	405
	Steptoe Ranch *(large pond)*	20.8	8.1	6.35	400
	Cordano Spring *(head)*	11.5	10.0	6.80	450
	Cordano Spring *(200 m downstream)*	9.0	14.0	6.95	420
Butte	Atwood Spring *(pond)*	16.5	6.7	6.30	500
	Atwood Spring *(100 m downstream)*	15.8	6.8	6.60	500
	Quilici Spring	8.8	6.1	6.40	295
	Taylor Spring *(pond)*	11.3	9.1	6.90	290
	Paris Ranch *(pond)*	6.5	12.4	7.25	320

TABLE 8. Diel changes in temperature (Temp., C), dissolved oxygen (D.O., mg/ℓ), and conductivity (Cond., μmho/cm^2) of Phalan Spring, February 1981.

Time (air temperature)	Spring Head			Downstream (≈125 m)		
	Temp.	D.O.	Cond.	Temp.	D.O.	Cond.
1200 (7.5 C)	20.25	7.0	315	18.75	7.3	310
1500 (3.5 C)	20.00	6.9	310	19.25	6.5	310
1800 (0.0 C)	19.50	4.5	310	19.00	5.6	310
2100 (-5.0 C)	19.50	4.4	275	18.50	5.5	280
2400 (-7.0 C)	19.50	4.5	290	18.50	5.5	290
0300 (-9.0 C)	19.50	4.5	290	18.00	5.5	300
0600 (-7.0 C)	19.50	4.6	295	18.50	5.5	290
0900 (4.0 C)	20.00	4.8	295	20.00	6.7	295
1200 (7.0 C)	20.00	4.8	315	20.00	7.3	315
Mean	19.75	5.1	299.4	18.94	6.2	300.0

the physical relationship between ambient temperature and the amount of oxygen which can be dissolved in water at saturation. However, a very interesting diel change in D.O. occurred in Phalan Spring; D.O. was high (>6 mg/ℓ) in the stream during the daylight hours and depressed (≃5 mg/ℓ) during the night. At the spring head the diel variation was greater—a maximum of about 7.0 mg/ℓ during mid-day and a minimum of about 4.5 mg/ℓ during darkness. The D.O. concentration of the spring water inflow is probably constant and relatively low (⩽4.5 mg/ℓ); during the light period, photosynthesis from periphyton and macrophytes results in elevated levels of D.O. During darkness, plant respiration decreases D.O. in the water and evolves CO_2. However, aeration and cooling which takes place in the course of the stream apparently more than compensates for the effect of plant respiration. At night the D.O. levels were consistantly about 1 mg/ℓ higher 125 m downstream than at the spring head. Likewise, the maximum daytime D.O. levels were slightly higher downstream.

Conductivity, which is a measure of the salinity of the water, also exhibited a diurnal change with the lowest values at night. But the causal relationships with the physical, chemical and biological parameters are not understood.

Mineral Analyses

I collected water samples from five relict dace habitats during December 1980 for gross mineral analysis by the DRI water chemistry laboratory (*Table 9*). Chemical analyses of four additional (and one duplicate) habitats were obtained from BLM (Water Analysis and Consulting, Inc. 1980) *(Table 10)*. Substantial variation was observed for total dissolved solids (TDS) as well as the qualitative composition of the constituents. TDS by the USGS (1979) summation technique, which approximates evaporation values, ranged from 190-1157.8 mg/ℓ. The spring waters were less than 330 mg/ℓ TDS and the pond waters were greater.

TABLE 9. Mineral characteristics of five relict dace habitats sampled from 12-03-80 to 12-05-80. Analyses were conducted by Desert Research Institute.

VARIABLE (mg/ℓ except where otherwise specified)	Alkali Pond (Ruby)	Franklin Lake (Ruby)	Steptoe Ranch (Steptoe)	Cordano Ranch (Steptoe)	Atwood Ranch (Butte)
Specific conductance (μ mho/cm at 25°C)	1840	730	432	458	537
Total dissolved solids (summation - USGS)	1157.8	444.3	255.6	265.3	325.7
SiO_2	12	1	20	15	16
pH	8.34	8.52	7.08	7.03	7.03
Alkalinity as bicarbonate (HCO_3^-)	1110	472	262	295	283
Cl^-	95.9	29.5	3.8	2.8	8.9
$SO_4^=$	115	11	18	13	56
Total anions (milliequivalents/liter)	23.30	8.78	4.77	5.18	6.05
Na^+	171	98.6	9.8	5.3	14.2
K^+	33.3	13.1	3.3	1.0	8.9
Ca^{++}	15.8	20.5	51.0	59.5	60.9
Mg^{++}	168	38.1	20.6	23.4	27.1
Total cations (milliequivalents/liter)	22.66	8.66	4.75	5.14	5.97

TABLE 10. Mineral characteristics of five relict dace habitats sampled from 4-30-80 to 9-23-80. Analyses were conducted by Water Analysis and Consulting, Inc., Eugene, Oregon for the Bureau of Land Management.

VARIABLE (mg/ℓ except where otherwise specified)	DATE	CURRIE* POND (Steptoe)	PHALAN CREEK (Goshute)	ATWOOD SPRING (Butte)	QUILICI SPRING (Butte)	ODGERS CREEK (Butte)
Temperature (C)	4-30	14	22	19	19	12
	7-15	16	23	21	20	20
	9-23	13	22	20	19	14
	MEAN	14	22	20	19	15
pH	4-30	7.8	8.0	7.7	7.7	8.1
	7-15	7.5	7.6	7.5	7.8	8.0
	9-23	7.5	7.5	7.1	6.8	7.4
	MEAN	7.6	7.7	7.4	7.4	7.8
Turbidity (NTU)	4-30	1.0	1.0	0.4	1.6	3.8
	7-15	0.4	1.3	0.4	0.4	5.2
	9-23	0.3	1.0	0.5	1.3	5.2
	MEAN	0.6	1.1	0.4	1.0	5.0
Dissolved Solids	4-30	350	216	375	219	216
	7-15	300	175	325	205	205
	9-23	330	190	325	180	190
	MEAN	330	190	340	200	200
Chloride	4-30	9.2	28	1	1	1
	7-15	35	4	7	5	3
	9-23	37	3	7	6	2
	MEAN	27	12	5	4	2
Calcium	4-30	8	13	19	13	14
	7-15	59	48	70	38	48
	9-23	17	29	36	25	24
	MEAN	28	30	42	25	29
Maganese	4-30	ND	ND	ND	ND	ND
	7-15	ND	ND	ND	ND	ND
	9-23	ND	0.05	ND	ND	ND
	MEAN	ND	0.02	ND	ND	ND
Potassium	4-30	0.8	ND	0.2	ND	ND
	7-15	0.8	0.1	0.2	ND	ND
	9-23	0.9	ND	0.4	0.2	0.1
	MEAN	0.8	0.03	0.3	0.07	0.03
Sodium	4-30	33	5	16	6	5
	7-15	40.4	6.6	20.1	8.9	6.3
	9-23	34	6	14	66	4
	MEAN	36	6	17	27	5
Sulfate	4-30	36	16	38	17	8
	7-15	22	18	40	20	17
	9-23	38	22	47	17	4
	MEAN	32	19	42	18	10
Bicarbonate	4-30	148	140	210	130	146
	7-15	158	144	222	130	120
	9-23	152	152	192	132	140
	MEAN	150	150	210	130	140
Carbonate	4-30	0	0	0	0	0
	7-15	0	0	0	0	20
	9-23	28	8	0	4	4
	MEAN	9	3	0	1	8
Total Coliform Bacteria (#/100 mℓ)	4-30	30	20	300	2200	1000
	7-15	15	ND	120	ND	700
	9-23	800	50,000	70	10	40
	MEAN	280	17,000	160	740	580
Fecal Coliform Bacteria (#/100 mℓ)	4-30	16	ND	5	6	3
	7-15	10	ND	60	ND	700
	9-23	500	10,000	30	10	20
	MEAN	180	3,300	32	5.3	240

*Relict dace no longer occur at Currie Pond

ND = Not detectable

Likewise, the pH of the springs was generally less than 8.0 and the ponds. The most saline habitats occurred in Ruby Valley, i.e., Alkali Pond and Franklin Lake; these were also the most alkaline: 1,110 and 472 mg/ℓ bicarbonate alkalinity, respectively.

Sulphate was the second most abundant anion in all habitats tested, except Franklin Lake where chloride was higher. Of the cations, calcium was at the highest levels in spring habitats, while sodium and magnesium comprised the largest proportion in Alkali pond and Franklin Lake.

Additional mineral analyses of former and present relict dace habitats are tabulated in the following references: Garside and Schilling (1979), thermal springs; Dudley (1967), Ruby Valley; and Clark and Riddell (1920), Steptoe Valley.

Nutrient Analyses

I collected nutrient samples from 11 relict dace habitats during December 1980, and compared these data with similar analyses conducted in five habitats by the BLM, April-September 1980 *(Table 11)*. Nitrate (NO_3-N) was generally at higher concentrations than orthophosphate (O-PO_4-P), however, nitrate was at or below detection limits (<0.1 mg/ℓ) in Alkali Pond, Franklin Lake, Atwood Ranch Spring, and Quilici Spring. The highest NO_3-N concentrations occurred in the Steptoe Valley springs (0.32-0.68 mg/ℓ), and the Paris Ranch Pond in Butte Valley (0.43 mg/ℓ); in all of these springs orthophosphate was at or below detection limits (<0.01 mg/ℓ). These five springs were all associated with cattle grazing.

In habitats where seasonal data are available, the highest levels of both orthophosphate and nitrate occurred in mid-summer. This observation seems aberrant since one would expect aquatic plants to utilize nutrients to the greatest extent during the season of maximum

TABLE 11. Nutrient analyses of selected relict dace habitats. Data were collected by the Desert Research Institute (DRI) and the Bureau of Land Management (BLM) during 1980.

Valley		Date	Agency	Orthophosphate $O-PO_4-P$:mg/ℓ	Nitrate NO_3-N:mg/ℓ
Ruby	Alkali Pond	12-3	DRI	0.03	<0.10
	North Narciss Spring	12-3	DRI	0.01	0.37
	Franklin Lake	12-3	DRI	0.03	<0.10
Steptoe	Lusetti Ranch - Grass Spring	12-4	DRI	<0.01	0.68
	Steptoe Ranch - Large spring above house	12-4	DRI	0.01	0.59
	Steptoe Ranch Springs Downstream from house	12-4	DRI	<0.01	0.62
	Cordano Ranch Spring head	12-4	DRI	0.01	0.32
	Currie Pond	4-30	BLM	0.13	0.20
		7-15		0.20	0.50
		9-23		ND	0.20
		MEAN		0.10	0.30
Goshute	Phalan Creek	4-30	BLM	0.03	ND
		7-15		0.1	0.1
		9-23		ND	0.2
		MEAN		0.04	0.1
Butte	Atwood Ranch Pond	4-30	BLM	0.07	ND
		7-15		0.30	ND
		9-24		0.10	ND
		MEAN		0.20	ND
		12-5	DRI	<0.01	<0.10
	Quilici Spring Pond	4-30	BLM	0.03	ND
		7-15		0.40	0.20
		9-24		ND	ND
		MEAN		0.10	0.07
		12-5	DRI	<0.01	<0.10
	Taylor Ranch Pond	12-5	DRI	<0.01	0.20
	Odgers Reservation	4-30	BLM	0.04	0.20
		7-15		0.30	0.20
		9-24		ND	0.10
		MEAN		0.10	0.20
	Paris Ranch Pond	12-5	DRI	<0.01	0.43

ND = Not Detectable

growth. One possible explanation is that after April snow melt and spring runoff from surrounding grazing lands contributes large amounts of allochthonous organic matter. Subsequent decomposition of this material in the sediments of springs and ponds may be a source of nutrients during the summer.

The nutrient levels observed in the habitats tested would not have direct detrimental effects on fish. However, ammonia and nitrites (which were not tested) are the nitrogen species toxic to fish, nitrates are relatively innocuous. The levels of nitrate measured in relict dace habitats are well below the 10.0 mg/ℓ NO_3-N which is criterion for domestic water supply. The primary importance of nitrates and orthophosphates is as nutrients for plant growth - this provides the energy base for aquatic systems and therefore must be kept within a range of natural balance.

LABORATORY DETERMINED ENVIRONMENTAL REQUIREMENTS

Temperature

Range finding tests were conducted on relict dace from Franklin Lake in the Ruby Valley. No mortality occurred at 29.0 C during 96 hours, and 100% mortality occurred at 34.3 C within 27 hours (10 fish/test). More definitive results were derived from the Butte Valley (Atwood Ranch) populations with four replicate tests over a range of 30-31 C *(Table 12)*. The 96-hr median tolerance limit (TL_{50}) for relict dace collected at the Atwood Ranch Spring was 30.6 C.

Concurrent tests on relict dace from Atwood Ranch and Phalan Spring at 30.7 C indicated that the latter population may be slightly more resistant to high temperatures. The Phalan Spring population experienced only 40% mortality at 30.7 C, while the Atwood Ranch Spring fish suffered 80% mortality. The higher temperature tolerance of the Phalan Spring population may be due to the long-term physiological acclimatization at 19.5-23 C compared to 16.5-21 C at the Atwood Ranch Spring *(Table 13)*.

Although the lower temperature limit was not determined, groups of relict dace were taken from springs in Butte, Goshute, and Steptoe Valleys at relatively warm water temperatures (10-20 C) and experienced near freezing temperatures in transit without excessive mortality. On one occassion about 96% of a sample of 80 dace survived a diel temperature change of 16.5 to 0.25 to 20.0 C during transportation from Atwood Ranch Spring in Butte Valley to the laboratory in Reno.

TABLE 12. Temperature tolerance tests (96-hr) of Butte Valley relict dace *(Relictus solitarius)* conducted from November 1980 - March 1981 in de-chlorinated Truckee River water at mean acclimation temperatures of 18-20 C. Sample size is five fish per test in replicate tests.

	MEAN CHEMICAL CHARACTERISTICS					
Mean test temperature	Sample size	Dissolved oxygen (mg/ℓ)	pH	Mean weight (g)	Number dead (96-hr.)	Percent mortality (10 fish)
30.0	9	6.4	8.75	1.82	0	0
30.0	"	6.5	8.20	1.46	0	
Control (21.6)	"	7.3	8.50	2.14	0	
30.6	8	6.8	8.76	2.08	2	50
30.6	"	6.8	8.17	2.40	3	
Control (22.7)	"	7.6	7.98	1.62	0	
30.7	18	6.5	8.54	2.24	4	80
30.7	"	6.6	8.36	2.28	4	
Control (21.3)	"	7.6	8.15	2.08	0	
31.0	7	6.1	8.39	1.68	5	100
31.1	"	6.1	8.51	3.20	5	
Control (21.7)	"	7.3	8.03	1.70	0	

TABLE 13. Environmental characteristics of selected relict dace, *Relictus solitarius*, habitats, April 1980 - February 1981.

Valley/Site	Date	Temperature (°C)	Total dissolved solids (mg/ℓ) Summation of all Constituents	Total dissolved solids (mg/ℓ) Summation (USGS 1979)	Total alkalinity (mg/ℓ $CaCO_3$)
Ruby					
Alkali Pond	12/80	2.0	1721	1157.8	912
Franklin Lake	12/80	3.5	683.8	444.3	387
Steptoe					
Steptoe Ranch	12/80	20.8	388.5	255.6	215
Cordano Ranch	12/80	11.5	415	265.3	242
Goshute					
Phalan Spring	04/80*	22	-	216	115
	07/80*	23	-	175	118
	09/80*	22	-	190	132
Butte					
Atwood Ranch	04/80*	19	-	375	172
	07/80*	21	-	325	182
	09/80*	20	-	325	158
	12/80	16.5	469.3	325.7	232
Odgers	04/80*	12	-	216	120
	07/80*	20	-	205	115
	09/80*	14	-	190	118

**Conducted by: Water Analysis and Consulting, Inc. 1980. Water Quality Study Wells Environmental Statement Area. Bureau of Land Management, Elko District.*

Compared to other families of freshwater fishes, the Cyprinidae generally occupy an intermediate rank of upper thermal tolerance. Through acclimation, an upper lethal temperature exceeding 30 C is achieved by most cyprinids; at the highest tested acclimation levels eight species ranged from 29.3 *(Rhinichthys atratulus)* to 38.6 C *(Carrassius auratus)* (Brett 1956).

The upper lethal TL_{50} herein determined for relict dace acclimated at 18-20 C, i.e. 30.6 C, falls within the range exhibited by other cyprinids. If the test fish were acclimated over a higher series of temperatures, it is likely that the upper lethal temperature would be significantly greater.

The maximum water temperature I recorded in a relict dace habitat was only 23 C, although summer temperatures in some shallow areas may be higher. However, different populations of relict dace are subjected to a wide variety of temperature regimes. Non-thermal springs and shallow ponds may have great daily and seasonal changes with minimum temperatures near freezing (e.g. Franklin Lake). At the other end of the spectrum are thermal springs which never vary more than a few degrees in terms of diel, seasonal, annual, and presumably over extremely long time periods. For example, the head of Phalan Spring exhibited less than a 1 C diel change in February when air temperature ranged from 7.5 to -9.0 C, and seasonal water temperature variation was only about 3 C. In addition, there are various types of intermediate gradations with respect to the temperature emanating from the springs and the changes which occur in the length of streams and/or depths of ponds.

Limited data exist on thermal tolerance levels of cyprinid species inhabiting the Great Basin. Speckled dace *(Rhinichthys osculus)* taken from intermittant Arizonan streams at <25 C had ultimately incipient upper lethal levels of 33 C for juveniles and 32 C for adults (John 1964). The Borax Lake chub, *Gila boraxobius*, is endemic to a thermal lake in southeastern Oregon which typically exhibits temperatures of 29-32 C, with extremes of 17-35 C (Williams and Williams 1980). Another cyprinid from the northwestern Great Basin, the desert dace *(Eremichthys acros)*, is endemic to thermal springs ranging from 18.5-40.5 C; this Nevadan species tolerated temperatures of 2-37 C in the laboratory when acclimated at 23 C (Nyquist 1963). Virgin River spinedace *(Lepidomeda mollipinis)*, native to the Colorado River System, had a 14-hr upper lethal temperature of 31.2-31.4 C when acclimated at 20 C (Espinosa and Deacon 1978).

In contrast, extensive research has been done on the thermal requirements of Cypinodontidae inhabiting the Death Valley region of the southern Great Basin. Pupfish (Genus *Cyprinodon)* acclimated at 10-20 C can tolerate temperatures of 39-40 C (Brown and Feldmeth 1971; Otto and Gerking 1973; Feldmeth et al. 1974).

Representatives of another cyprinodont genus *(Crenichthys)* are remnants of Pluvial river systems in the southeastern Great Basin. *Crenichthys baileyi* inhabits springs in the Moapa Valley at constant temperature of 32.2 C (Kopec 1949). In the Moapa River *C. baileyi* and *Moapa cariacea* (Cyprindae) occupied habitats at temperatures of 27-32 C and 19.5-32 C, respectively (Deacon and Bradley 1972). *C. baileyi* and *C. nevadae* live in various spring outflows in the White River Valley and Railroad Valley, respectively, at temperatures ranging from 21 to 37.3 C (Hubbs et al. 1967). *C. nevadae* were observed in the Lockes Ranch spring complex at temperatures of 18.3-37.8 C (Baugh and Brown 1980).

Although individuals may survive for short periods of time at extremely high temperatures, the maximum constant temperature occupied by a reproducing population of desert fish is rarely greater than 35 C (Soltz and Naiman 1978). This may be attributed to the differential tolerance of various life stages; e.g., Amargosa pupfish *(Cyprinodon nevadensis)* juveniles are most tolerant of extreme temperatures, with adults intermediate, and eggs least tolerant (Shrode 1975, Shrode and Gerking 1977). The reproductive tolerance range (≥50% hatch) of *C. nevadensis* was 24-30 C or one-seventh the critical thermal tolerance range (Shrode and Gerking 1977). This example illustrates that multiple criteria are necessary to establish the thermal requirements of a fish species. Thus, the TL_{50} determined in this study at a single acclimation regime is a useful baseline datum but is not comprehensive.

In general, temperature has a profound effect on the physiology, ecology, and differientation of desert fishes. Rates of evolution, life histories, reproductive strategies, and consequent adaptations to the environment by endemic fishes vary in response to the thermal characteristics of their habitat (Soltz and Naiman 1978). High temperature is believed to have accelerated the rate of evolution of endemic fish inhabitating warm springs by increasing the mutation rate and number of generations per year. The temperature regime can also have direct effects on meristics (Miller 1950). The dwarfed Ruby Valley population of relict dace is the only form which is greatly differientated; the reduced size may be due to environmental conditions rather than genetic differences (Hubbs et al. 1974).

Brown and Feldmeth (1971) hypothesized that evolution of fish populations in Great Basin springs which exhibit great temperature variation, compared to those with constant temperatures would result in genetic differences with respect to thermal tolerance. They experimentally determined, however, that differences between populations of *Cyprinodon* in their ability to withstand extreme temperatures are dependent solely on physiological acclimation temperatures with no evidence of genetic differences in short-term thermal tolerances. Five taxa of morphologically distinct species of *Cyprinodon* were found to be very similar in terms of biochemical genetics even though the ecological differences among their habitats suggest the existence of markedly different selective forces (Turner 1974). In contrast, Hirshfield et al. (1980) discovered small but statistically significant differences between the thermal tolerances of *Cyprinodon nevadensis* and *C.n. mionectes* when reared under identical environmental conditions. They concluded the differences represented genetic divergence which was biologically important even though acclimation temperatures exert a great effect.

C. diabolis which has been isolated in a thermally constant spring for 30,000 years remains capable of tolerating as wide a range of temepratures as *C. salinus* and *C. nevadensis* which encounter temperature fluctuations from 0 to 40 C in their present habitats (Brown and Feldmeth 1971). Likewise the Atwood Ranch and Phalan Spring relict dace populations were moderately eurythermal even though their respective habitats are stenothermal. However, it is not known if relict dace inhabiting fluctuating thermal environments have a wider thermal tolerance than populations inhabiting a stenothermal environment.

TDS-Alkalinity

Relict dace tolerated total alkalinity ($HCO_3^- + CO_3^=$ as $CaCO_3$) and corresponding TDS of 2,580 mg/liter and 11,043 mg/liter, respectively, for 96 hours without experiencing any mortality *(Table 14)*. TDS levels of 15,759 and 20,475 mg/liter resulted in 100% mortality of both populations of relict dace tested. Analysis of variance illustrated a significant difference in resistance times by concentrations ($P<0.001$), fish population ($P<0.05$) and interaction between the main effects ($P<0.001$). An a-posteriori comparison showed that the Butte Valley (Atwood Ranch) fish were significantly

TABLE 14. Salinity tolerance tests (96-hour) of relict dace, *Relictus solitarius*, conducted during December 1980 and March 1981. The first series of bioassays tests interaction with temperature, the second series tests differences by fish population. Sample size is five fish per test.

TDS (mg/ℓ)	Population: valley (habitat)	MEAN CHEMICAL CHARACTERISTICS Sample Size	 Temp. (°C)	 D.O. (mg/ℓ)	 pH	Mean weight (g)	Number dead	Percent mortality
157 (Control)	Butte (Atwood)	9	21.6	7.3	8.50	2.14	0	
	"	"	30.0	6.4	8.75	1.82	0	0
	"	"	30.0	6.5	8.20	1.46	0	
2,845	Butte (Atwood)	"	21.9	7.4	9.11	1.78	0	0
	"	"	30.0	6.4	9.20	1.18	1	20
5,652	Butte (Atwood)	"	20.9	7.3	9.21	1.60	0	0
	"	"	29.9	6.4	9.20	2.22	3	60
11,043	Butte (Atwood)	12	21.4	7.6	9.24	2.14	0	0
	Goshute (Phalan)	"	21.4	7.6	9.24	2.00	0	0
15,759	Butte (Atwood)	7	21.8	7.6	9.25	2.22	5	100
	Goshute (Phalan)	4	22.0	7.4	9.13	1.92	5	100
20,475	Butte (Atwood)	2	22.3	7.1	9.09	1.90	5	100
	Goshute (Phalan)	"	22.3	7.1	9.09	1.80	5	100
157 (Control)	Butte (Atwood)	12	21.4	7.6	8.35	1.98	0	0
	Goshute (Phalan)	"	21.4	7.6	8.30	6.02	0	

more resistant to concentrated alkaline-saline waters than the Goshute Valley (Phalan Spring) population ($P<0.05$). The resistance time of Atwood Ranch fish was about twice that of the Phalan Spring fish at both the 15,759 and 20,475 mg/liter levels *(Table 15)*.

There exists an apparent interaction between temperature and salinity tolerances of relict dace *(Table 14)*. No mortality occurred at low temperatures (21-22 C) over a range of TDS from 157 to 5,652 mg/liter. But at an elevated temperature (30 C) differential mortality occurred: 0, 20, and 60% at TDS levels of 157, 2,845, and 5,652 mg/liter respectively.

The relict dace has experienced a variable evolutionary environment during the past 2 million years in the Great Basin. Numerous cycles of Pluvial filling and interpluvial desiccation of large Pleistocene lakes occurred. Concomitant changes in the salinity of the lacustrine habitats undoubtedly took place. The variable content of TDS presumably has been a factor of considerable importance in the survival or extinction, and probably in the speciation of the populations of endemic fishes (Hubbs et al. 1974). During the past 10,000 years the lacustrine habitats of the relict dace have completely dried up and the species persists in remnant springs. The vast reduction of surface water to isolated springs is the outstanding feature of the habitats of native fishes in the Great Basin (Hubbs et al. 1974).

Chloride is the dominant anion of remnant Great Basin lakes, although the most characteristic constitutent is carbonate and bicarbonate alkalinity. For example Pyramid and Walker Lakes (remnants of Lake Lahontan) have TDS concentrations of about 5,500 and 11,000 mg/liter, respectively. Approximately 65% of the TDS is sodium chloride (NaCl) and about 25% is total alkalinity.

TABLE 15. Mean resistance time of Atwood Ranch (A) and Phalan Spring (P) relict dace, *Relictus solitarius*, to highly alkaline-saline waters. Sample size is five fish per test.

TDS (mg/ℓ)	Population	Mean resistance time (Minutes)	95% Confidence Interval (Minutes)
11,043	A	Indefinite (>5,760)	-
	P	Indefinite (>5,760)	-
15,759	A	1,907	1,204 - 2,610
	P	848	280 - 1,416
20,475	A	213	121 - 305
	P	111	70 - 152

Alkalinity is the component of TDS which is generally toxic to fish, while NaCl is relatively innocuous at comparable concentrations (Beatty 1959; Mitchum 1960; Knoll et al. 1979). Likewise one of the most distinctive features of the native fish fauna which evolved in Nevada's Pleistocene lakes (e.g. *Salmo clarki henshawi* and *Gila bicolor)* is the ability to tolerate highly alkaline waters.

In contrast, euryhaline anadromous species (e.g. *Salmo gairdneri)* which live in ocean water at a TDS of 35,000 mg/liter (≈86% NaCl) were unable to survive in Walker Lake at about 11,000 mg/liter TDS (Knoll et al. 1979). Similarly a brackish-marine species., *Scianops ocellata* which occurs in Texas at a TDS range of 6,400 to 16,000 mg/liter was unable to tolerate 50 - 100% concentrations of Walker Lake water (Koch et al. 1979). Thus alkalinity is the constituent of TDS which has been implicated in fish toxicity in Great Basin waters; however, the experiments conducted on relict dace were not designed to separate the effects of alkalinity from TDS.

The elevated salinity level which relict dace tolerated (11,043 mg/liter TDS) is over six times the maximum TDS level of any current relict dace habitat measured. The corresponding total alkalinity level (2,580 mg/liter) represents nearly three times that in any current habitats. The spring habitats are generally <250 mg/liter total alkalinity and <500 mg/liter TDS *(Table 13)*; the most saline habitats are ponds in the Ruby Valley which exhibit total alkalinity levels as high as 912 mg/liter (TDS = 1,721 mg/liter). I hypothesize that relict dace evolved the physiological mechanisms to withstand highly saline-alkaline waters during the desiccation of their lacustrine environment. When the lakes completely dried up, the only surviving fish were restricted to permanent spring systems exhibiting relatively low alkalinities; however the relict dace still maintain the genetically programmed ability to survive in concentrated saline waters.

In contrast to relict dace habitats, Cyprinodont environments in the southern Great Basin can be extremely saline - as much as 4.5 times that of sea water, composed predominantly of NaCl (Hunt et al. 1966). The composition of one saline habitat, Cottonball Marsh, was about 78% NaCl with alkalinity not listed as a constituent (LaBounty and Deacon 1972). During laboratory studies with the ionic composition approximating that of sea water, the Cottonball Marsh pupfish *(Cyprinodon milleri)* survived at 88,000 mg/liter TDS with a few individuals tolerating 130,000 mg/liter for several weeks (Naiman et al. 1976). Numerous field observations of various *Cyprinodon* species living at salinities greater than 90,000 mg/liter are documented in the literature (Barlow 1958, Deacon and Minckley 1974).

Thus relict dace can tolerate only a fraction of the TDS which Cyprinodonts exist at. This is probably a reflection of the differences in their respective evolutionary environments. However, the ionic composition of their environments and test media may also be a critical factor; i.e., the alkalinity component could affect the TDS tolerance of both taxons.

Salinity bioassays on relict dace at normal and elevated temperatures demonstrated a synergistic effect. Brett (1960) points out that with the multiple role of temperature bringing increased attention to the problem of interaction, emphasis will shift away from the singular effects of temperature to synergistic effects within the overall characteristics of environments which permit survival of the species. In his work with the euryplastic *Cyprinodon macularius,* Kinne (1960) showed that the combination of temperature and salinity was of basic physiological importance; the effects of a given temperature depend on the salinity and vice versa. Similarly when dealing with the habitat requirements of relict dace, the synergistic relationships of salinity and temperature are important with respect to their physiology and ecology.

LIFE HISTORY

Size structure

The age composition of a fish population is an important aspect of its life history. In conjunction with length, weight, fecundity, and relative abundance; age data may provide information on stock composition, age at maturity, life span, mortality, growth, and production. The most frequently used method of age determination in a temperate region is the measurement and interpretation of growth zones on hard parts, i.e. scales, fin rays and spines, operculums, and otoliths. However, a prerequiste of this method is seasonality of environmental conditions, specifically growth-related parameters such as temperature and food supply. Therefore, in thermal springs where the environment remains relatively constant throughout the year the growth-ring technique would likely not be valid.

The length composition of a fish population will often exhibit modes which correspond to age classes, especially for the younger age-groups (Tesch 1971). These modes, which suggest mean fish lengths at successive ages, are most pronounced in fish with a short spawning season and rapid and uniform growth. This technique may give an indication of the age structure of relict dace, however, if the spawning season is not discrete (i.e. protracted over a long period) the modes may correspond to cohorts and not annual classes per se.

Historical standard length frequencies of relict dace indicate that various populations naturally have different size compositions *(Table 16)*. For example the Ruby and Steptoe Valley populations are the only ones well represented in the 15-30 mm size classes, while

TABLE 16. Length frequencies (percent by class) of 1,888 relict dace sampled from five valleys in northeastern Nevada 1934-1942. Data are derived from Hubbs et al. (1974), Table 38.

Size Class-Standard Length (mm)	Percent by Length Class					
	Ruby (Pothole Spring)	Butte (Kirkpatrick Ranch)	Goshute (Johnson Ranch)	Steptoe (Dairy Ranch)	Spring (Stone House)	Total
Date	*9/12/34*	*6/27/42*	*6/22/42*	*8/23/38*	*7/6/38*	*1934 - 1942*
15-20	1.3	0	0.4	3.6	0	1.1
20-30	25.5	0	0.4	29.2	2.0	10.5
30-40	29.6	15.7	28.5	3.6	31.8	23.3
40-50	40.6	33.1	49.2	17.5	20.7	35.0
50-60	2.8	17.5	15.7	36.9	23.3	19.2
60-70	0.3	8.4	3.0	6.8	15.2	6.0
70-80	0	13.2	1.4	2.2	6.4	3.3
80-90	0	6.6	0.3	0.3	0.6	0.9
90-100	0	4.8	0.3	0	0	0.5
100-110	0	0.6	0.4	0	0	0.2
110-115	0	0	0.3	0	0	0.1
Sample Size	318	166	695	366	343	1,888

the Butte and Goshute populations are the only ones represented in size classes >90 mm. However, the length increments are not sufficiently small to indicate cohorts or year classes.

I analysed fork length data from several sections of Odgers Creek (Butte Valley) collected by Nevada Department of Wildlife and Bureau of Land Management during 1980 *(Figure 4)*. The 2 mm length increments accentuate various modes which probably represent different age-segments of the population. The individual length frequencies show that the age composition varies in the different reaches of the creek; e.g., juveniles may be concentrated in certain areas, some areas have representatives of all age classes, and other areas may contain a relatively uniform age structure only of mid-size fish.

In general there is good correspondence among the length classes represented by the various modes in the individual sections of Odgers Creek. Thus the combined length frequency may give an indication of age groups *(Figure 5)*. Seven apparently discrete, length groups exist in the population: 20-40, 40-52, 52-70, 70-82, 82-96, and >100 mm. These size groups may or may not represent year classes depending upon the spawning and growth regimes of the species.

Length data I collected from the Butte Valley Quilici Spring population *(Figure 6)* roughly correspond to the same length groups observed in Odgers Creek. All of the modal groups are represented in the Quilici sample, except for the >100 mm group. The largest (oldest) fish are naturally the least abundant age group. If the sample size were larger it is likely that a few of these rare, old fish would be captured. The same principle is true for the Phalan Spring and Steptoe Ranch Spring samples which have a low sample size. In fact during diel sampling, I captured several large individuals in Phalan Spring-including one superatenuated fish >100 mm; however I did not record length from these catches. The

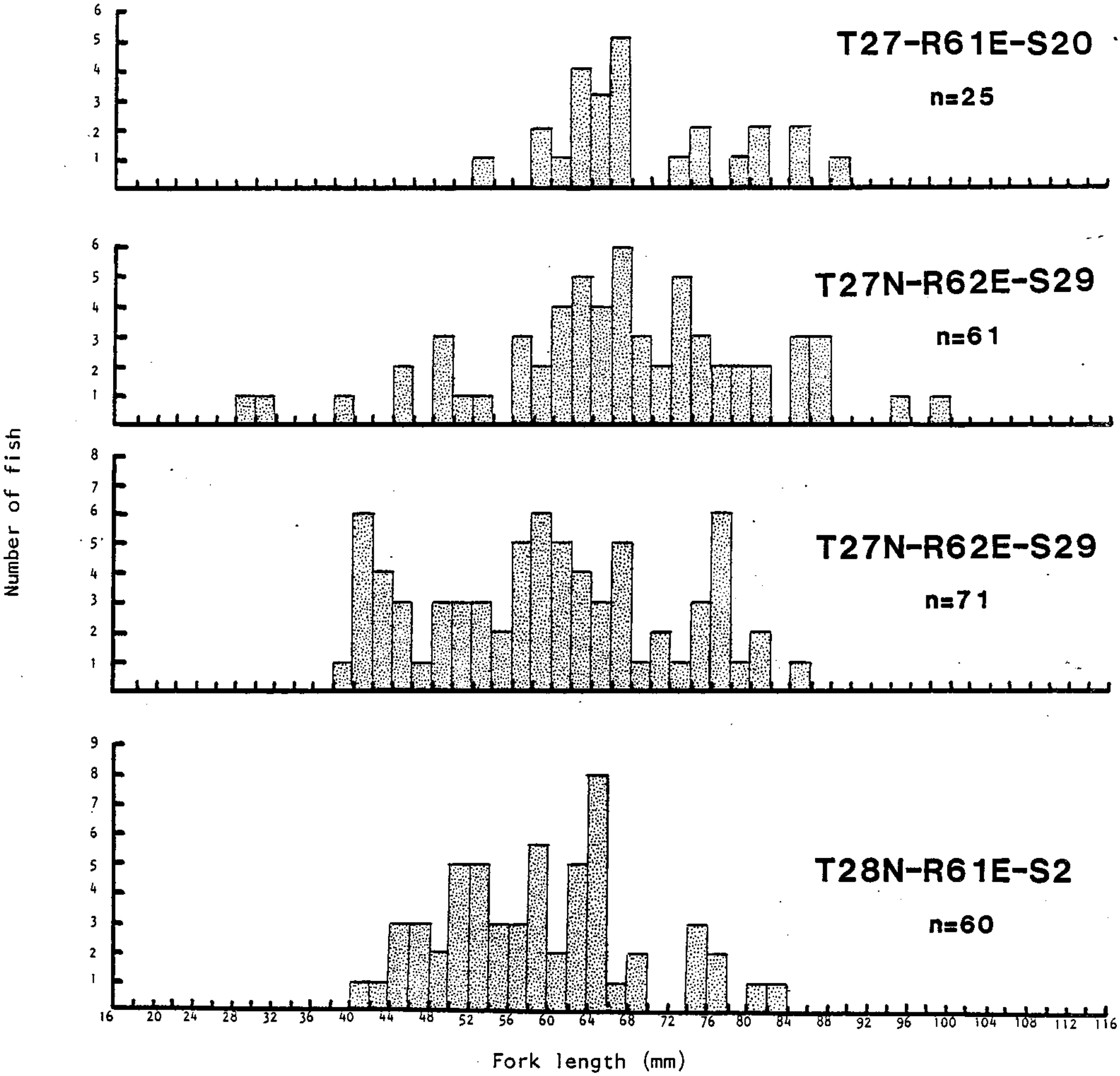

FIGURE 4. Individual length frequency distributions of relict dace sampled from nine sections of Odgers Creek, Butte Valley by NDOW and BLM during May 5-8, 1980.

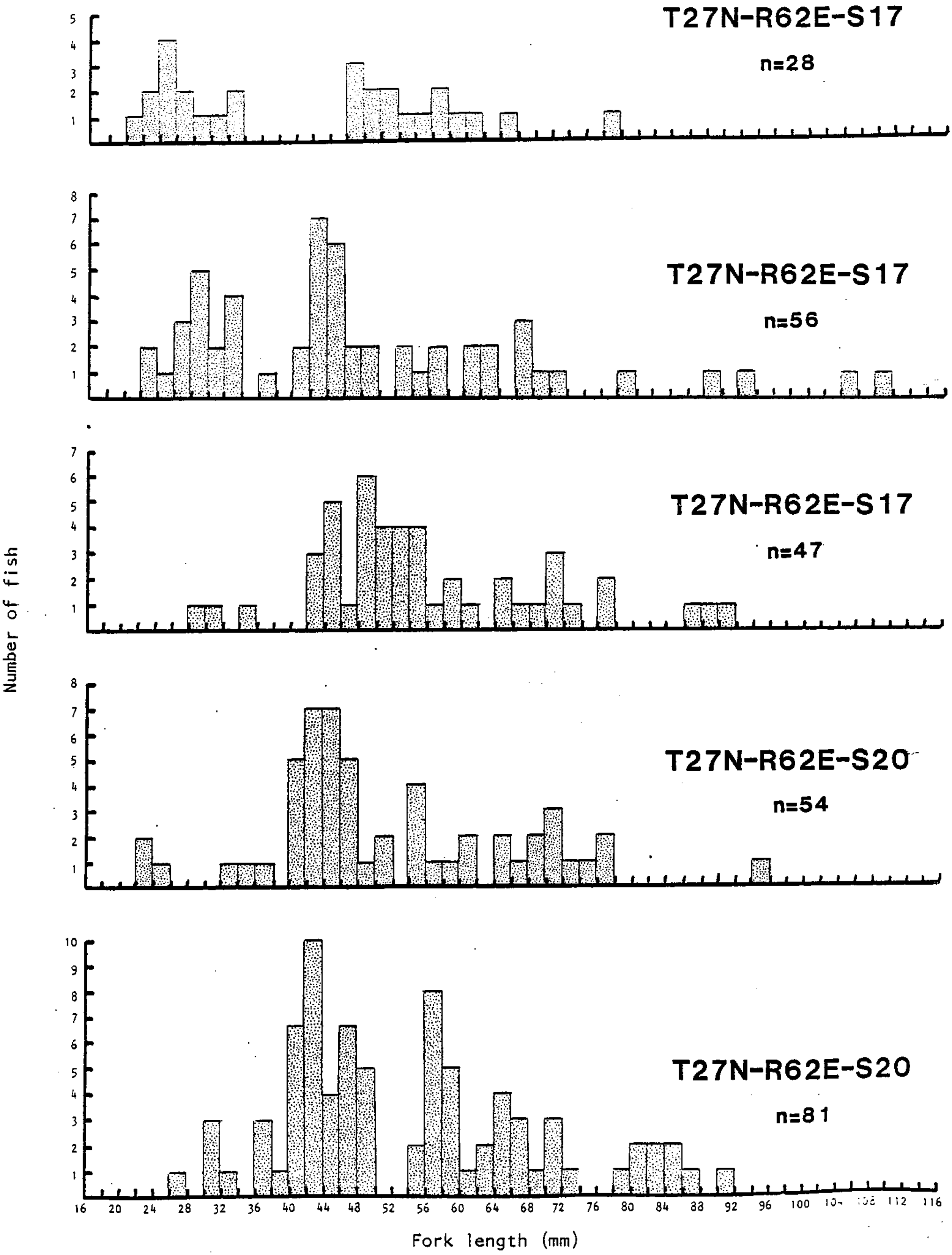

FIGURE 4. (Continued)

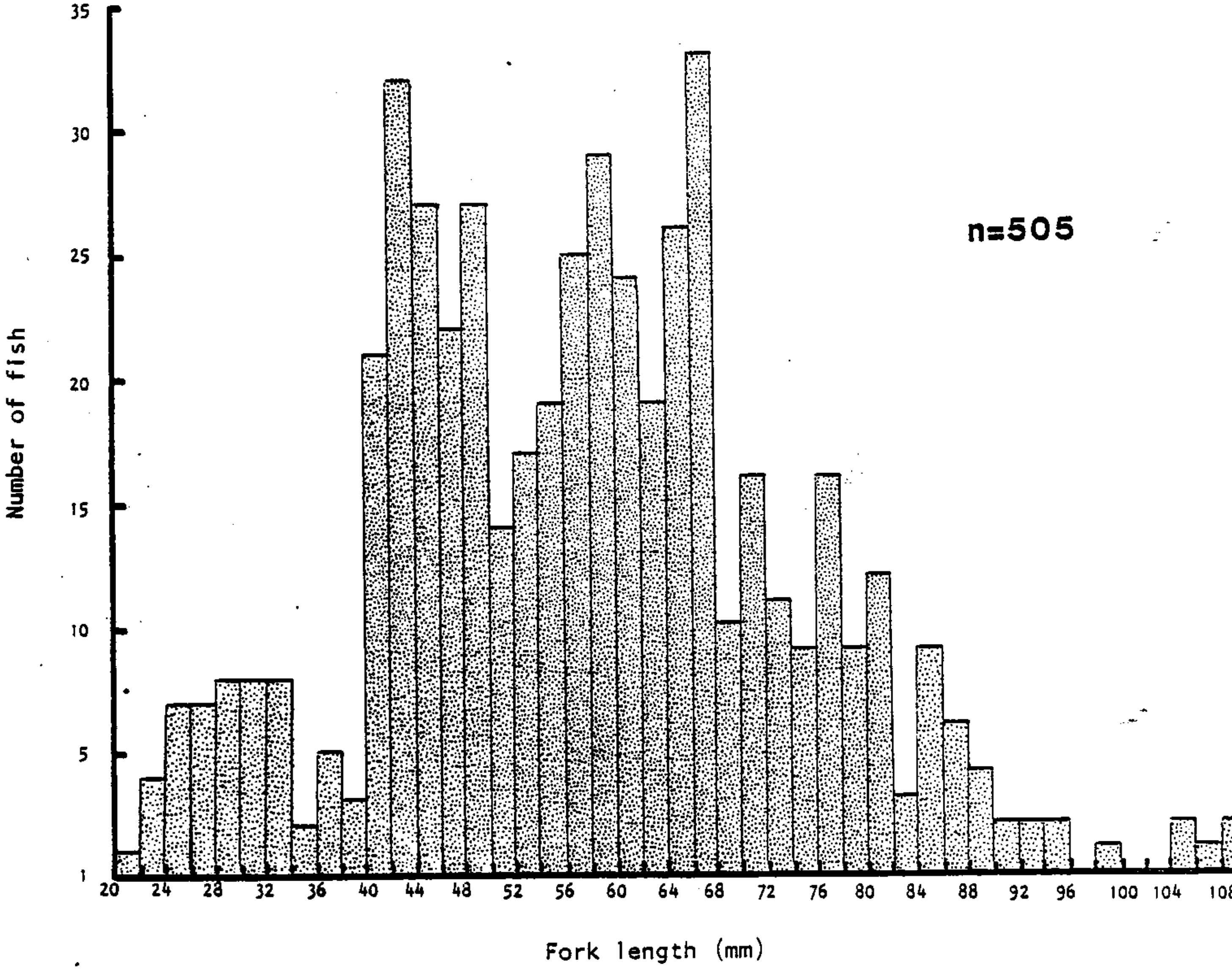

FIGURE 5 . Combined length frequency of 505 relict dace sampled from 11 sections of Odgers Creek, Butte Valley by NDOW and BLM during May 5-8, 1980.

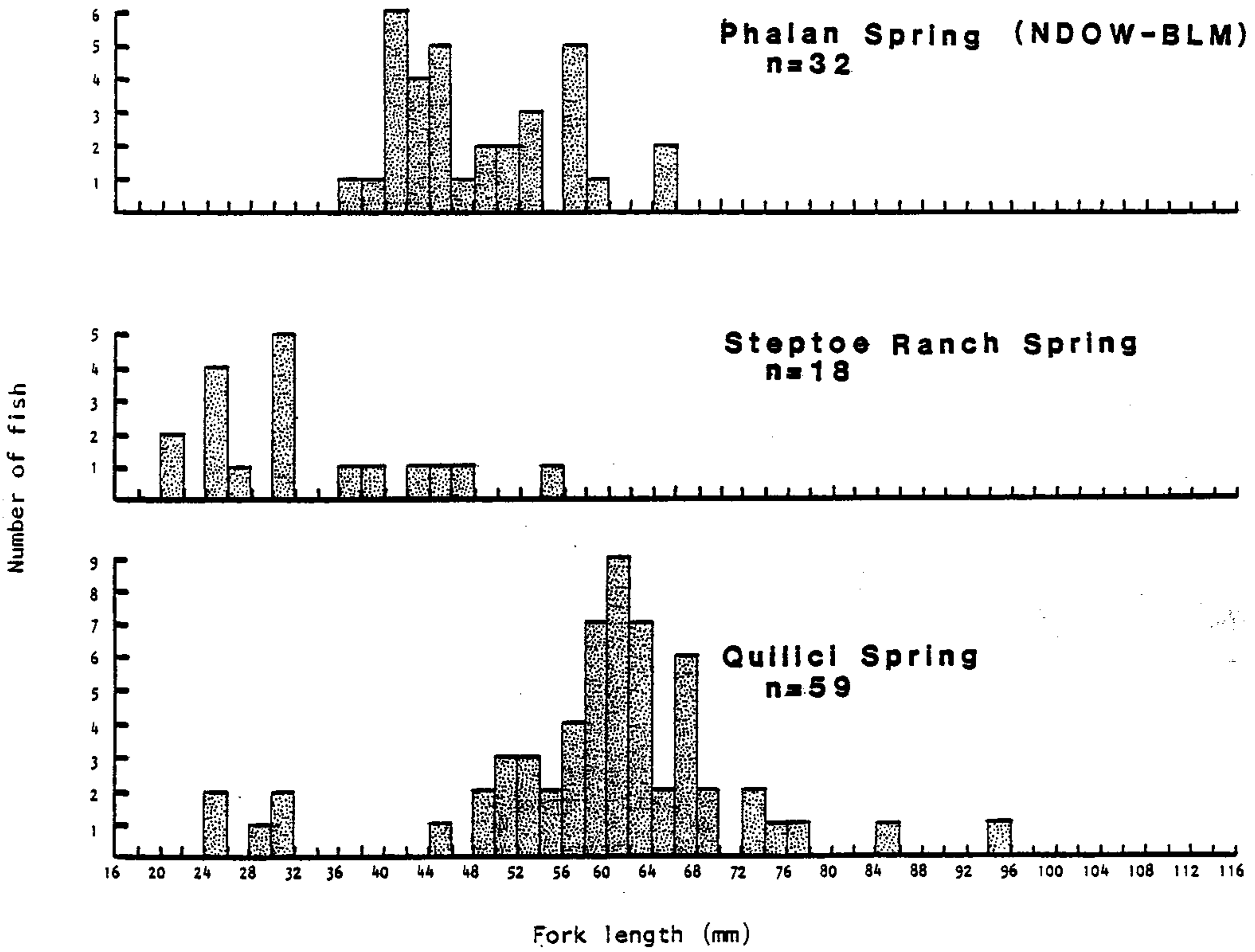

FIGURE 6. Length frequencies of relict dace sampled from: Phalan Spring, Goshute Valley (May 1980); Steptoe Ranch Spring, Steptoe Valley (October 1980); and Quilici Spring, Butte Valley (October 1980).

Steptoe Ranch sample of only 18 fish was comprised entirely of dace <60 mm. Even though this is an inadequate sample size to obtain a representative length frequency distribution, it is consistant with the sample from Steptoe Valley taken by Hubbs et al. 1938 *(Table 16)*. This sample was also predominantly comprised of fish <60 mm.

The size structure of three Ruby Valley populations illustrates a marked departure from those of Butte and Goshute *(Figure 7)*. Hubbs et al. (1974) considered the Ruby Valley population to represent the most highly differentiated (dwarfed) form of relict dace; meristic counts were lower but the differences were not sharp enough to warrant suspecific separation.

The size compositions of North-east Spring and Franklin Lake are similar (the spring lies just to the east of intermittant Franklin Lake). Two or three size groups are represented in these populations. Fish <40 mm are probably young-of-the-year; thus, these populations are apparently comprised primarily of young fish-predominantly one year olds with a few older. The young age composition of Franklin Lake relict dace may be explained by the fact that it periodically desiccates, usually on an annual basis.

The Narciss Spring population exhibits a much different size composition, one more closely resembling those of Butte Valley. The reason for this is probably environmental. Narciss Spring has a relatively high volume of flow (compared to North-east Spring) and a long course. Thus conditions are similar to the springs in Butte Valley; and are more conducive to growth, longevity and a stable age structure.

In comparing data from Hubbs et al. (1974) to current collections it should be noted that the lengths of the former fish were recorded as standard length while the latter were recorded as fork length. Thus for a fish of a given standard length, e.g. 100 mm, a slightly

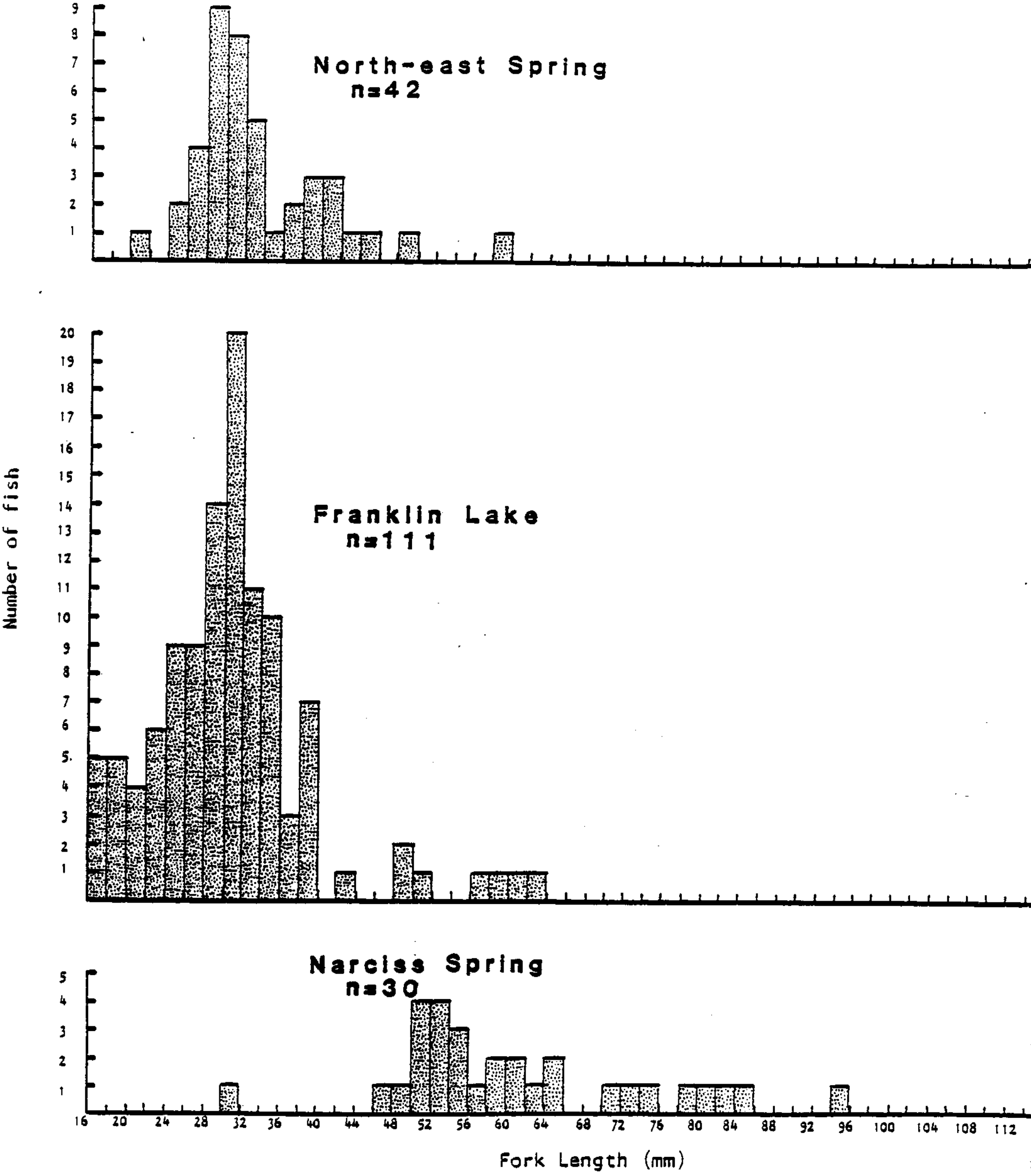

FIGURE 7. Length-frequencies of relict dace sampled from three populations in Ruby Valley, (September 1980).

greater length would be measured in terms of fork length. This is relevant to comparison of relative length frequencies; for example the collections made by NDOW and BLM in Odgers Creek had a relatively high proportion of fish >100 mm fork length-this proportion may be somewhat lower if measured in standard length.

The statistical relationship between standard and fork lengths has not yet been quantified for relict dace. A third length measurement, total length, is commonly used in fisheries biology. I measured both lengths from a sample of fish (n=12) from Narciss and Quilici Springs - the mean ratio of fork to total length was 0.94:1, with little variation.

The length-weight relationship for relict dace is curvilinear *(Figure 8)*; thus as the fish grows it acrues more weight for a given increase in length. The length-weight relationship for the Quilici Spring sample was described by a logarithmic linear relationship: $\log_{10} W = 1.44 + 0.59 \log_{10} L$ $(n=49, r^2=0.96)$; where W is weight is grams and L is fork length in millimeters.

Condition factor $(K = W \times 10^5/L^3)$ is related to the length-weight relationship in that weight (volume-related) is a cubic function of length. For isometric growth the condition factor (K) would equal one. Thus, it is a measure of fitness or well being of a fish. If the species-specific mean $-K$ is known, a given fish can be evaluated for robustness; also populations can be compared in terms of the suitability of their respective environments for a fish species.

The overall K of 44 relict dace from Quilici Spring was 1.19 *(Table 17)*. Condition was highest for the smallest length class evaluated (45-54 mm) and generally decreased with increasing length. Thus the older fish are not quite as robust or deep-bodied as the younger fish.

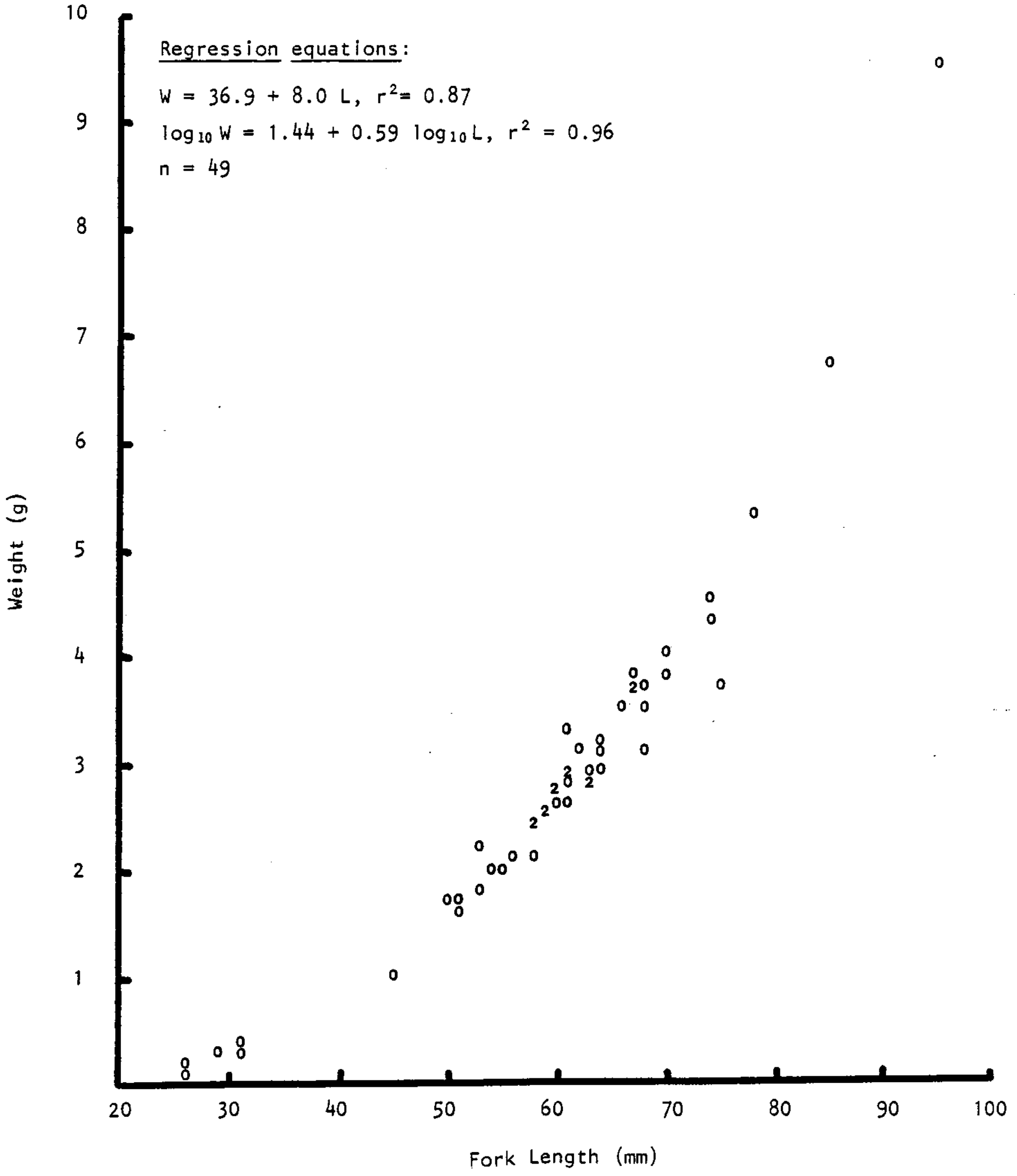

Figure 8. Length-weight relationship of relict dace from Quilici Spring, Butte Valley. Fish were sampled on 10/01/80 and measured alive in the laboratory.

TABLE 17. Condition factor, by size group, of relict dace sampled from Quilici Spring, 10-01-80.

Fork length (mm)		Sample Size	Conditon Factor	
Class	Mean		Mean	Range
45-54	51.0	7	1.272	1.206-1.478
55-59	57.6	7	1.195	1.076-1.230
60-64	61.9	15	1.220	1.106-1.454
65-69	67.3	7	1.174	0.986-1.263
70-95	77.6	8	1.080	0.877-1.166
45-95	63.2	44	1.192	0.877-1.478

Reproduction

It is likely that the reproductive strategy of relict dace populations varies with respect to the environment, particularly the thermal regime. Relict dace is a very prolific fish, with a long breeding season, extending at least from late June to mid-September (Hubbs et al. 1974). They observed extremely small dace in a slough below Cave Creek in Ruby Valley on September, 1934-indicating late spawning. Both males and females collected from Narciss Spring in Ruby Valley September 30, 1980 exhibited "ripe" gonads. The mean gonadal-somatic index *(GSI = ovary weight* X *100/ total fish weight)* was 8.5 for a sample of four ripe females *(Table 18)*. This high percentage of ovarian tissue indicates these fish were in reproductive condition. Mr. Eric Sprado, present owner of the "Atwood Ranch" in Butte Valley, has observed young relict dace in his pond (constant temperature, ≈ 16 C) at all times of the year.

TABLE 18. Gonadal somatic index (GSI) of four female relict dace from Narciss Spring, Ruby Valley, 10-01-80.

	Fork Length (mm)	Weight (g)		GSI
		Fish	Ovary	
	81	7.9	0.9	11.4
	89	10.4	0.7	6.7
	83	9.7	0.6	6.2
	79	9.2	0.9	9.8
MEAN	83	9.3	0.8	8.5

Actually very little quantitative data exist on the reproductive biology of relict dace. The fecundity, i.e., number of eggs/female/year, is unknown. Spawning behavior is also unknown: however, Hubbs et al. (1974) speculated that relict dace spawn on vegetation since the soft mud substrate, typical of relict dace spring habitats, is often anaerobic. From length-frequency distributions Hubbs et al. (1974) concluded that: (1) both sexes spawn first as yearlings, (2) the smallest yearlings reproduce in their second year of life (3) few males breed at an older age, and (4) many females reproduce when two or more years old.

Thus, additional research is needed to determine: age-specific fecundity, spawning behavior, environmental requirements of eggs and larvae, and the reproductive biology of the species in thermal compared to non-thermal habitats. The fact that seasonally large populations persist in habitats which periodically desiccate (e.g. Franklin Lake) is an interesting facet of the reproductive biology and population dynamics of relict dace. It is probable that nearby springs act as refugia for a reproducing population which seasonally colonizes the intermittant lake. The mature fish which emigrate into Franklin Lake probably experience a very high mortality rate (along with the offspring) as the lake dries up in the fall. This yearly cropping of the population may explain the youthful age-composition of both Franklin Lake and North-east Spring. Another possible explanation of the intermittant-habitat phenomenon is an annual reproductive cycle where eggs which are spawned in the late fall, resist desiccation during winter and hatch when the lake re-fills with water in the spring. This is an extreme reproductive strategy for fish, but delayed hatching does exist in the genus *Fundulus*, Family Cyprinodontidae (Harrington 1959; Abel and Castagna 1975; Cokendolpher 1976).

Feeding Habits

Fish are generally opportunistic, i.e., they feed on what ever organisms that are available in their environment, and can be readily ingested. I sampled five springs representing three different valleys (Steptoe, Butte, and Ruby) for macroinvertebrate organisms ***(Table 19)***. A total of 615 organisms were identified and enumerated representing 14 Families and seven Orders of insects, as well as crustaceans, snails, clams, aquatic earthworms, and leeches. Amphipods and gastropods were the most prevalent forms, comprising over 80% of the organisms in the samples. I observed leeches in various habitats; they may be more abundant than the samples indicate.

Preliminary stomach analysis indicates that relict dace eat insects, amphipods, ostracods and leeches ***(Table 20)***. This is not a definitive study, however, and further studies should be done in various types of habitats on a seasonal basis, stratified by fish size groups. *Gila boraxobus* from southeastern Oregon and *Gila alvordensis* from southeastern Oregon and northwestern Nevada fed primarily on chironomid larvae, cladocerans, copepods, ostracods,

TABLE 19. Macroinvertebrate samples from five relict dace habitats collected by filtering the substrate through a Ponar screen, September-December, 1980.

	Number of Organisms (Family) by Habitat (date)					TOTAL	
	Cordano Ranch Spring (12/04/80)	Steptoe Ranch Spring (10/08/80)	Atwood Ranch Spring (12/05/80)	Quilici Spring (10/01/80)	Narciss Spring (09/30/80)	Families	Organisms
ODONATA							
(a) Anisoptera (dragonflys)	Aesnnidae-1	Libellulidae-8	Aeshnidae-6 Libellulidae-7	0	0	2	22
(b) Zygoptera (damselflys)	0	Coenagriidae-7	Coenagriidae-6	Coenagriidae-6	0	1	19
TRICHOPTERA (caddisflys)	Limnephilidae-3	0	0	0	0	1	10
HEMIPTERA (true bugs)	Corixidae-4 Notonectidae-2	Belostomatidae-11 Gerridae-1	Belastomatidae-1	Belastomatidae *Lethocerus angustipes-2*	Corixidae-3	4	24
COLEOPTERA (beetles)	0	2 (adult shells)	0	Dytiscidae-1 Hydrophilidae *Hydrophilus insularus-1*	0	3	4
DIPTERA (flys)	Chironomidae-1	0	0	0	0	1	1
LEPIDOPTERA (butterflys)	0	1	0	0	0	1	1
EPHEMEROPTERA (mayflys)	0	0	1	0	0	1	1
AMPHIPODA (seeds)	Talitridae *Hyalella azteca-6* Gammaridae *Gammarus-40*	Talitridae *Hyalella azteca-97*	Gammaridae *Gammarus-20*	Talitridae *Hyalella azteca-5*	Gammaridae *Gammarus-4*	2	172
GASTROPODA (snails)	(≥two types) 256	(≥two types) 64	4	3	2	>2	329
PELECYPODA (clams)	2	14	0	0	0	1	16
OSTRACODA (seed shrimp)	0	4	0	0	0	1	4
OLIGOCHAETA (earthworms)	0	6	0	0	0	1	6
HIRUDINEA (leeches)	0	6	0	0	0	1	6
Families	10	13	7	6	3	22	x
TOTAL:							
Organisms	322	221	45	18	9	x	615

TABLE 20. Stomach contents of 12 relict dace from Narciss Spring (N) collected on 9-30-80 and from Quilici Spring (Q) on 11-10-80.

Habitat	Fork Length (mm)	Weight (g)	Number of Food Items			
			Insects	Amphipods	Ostrocods	Hirudinea
N	81	7.9	0	0	3	0
N	89	10.4	1 (leg)	2(+ pieces)	0	0
N	83	9.7	0	1 pieces	0	0
N	79	9.2	2	0	0	0
N	75	7.5	1 (perhaps Collembala)	0	0	1
N	58	3.4	0	0	145	0
N	51	2.6	EMPTY			
N	54	2.5	EMPTY			
N	50	2.4	EMPTY			
N	51	3.0	EMPTY			
Q	57	3.6	EMPTY			
Q	61	3.7	3 (one may be Hymenoptera)	0	0	0

and diatoms; they were very exploitative of organisms seasonally available in the environment (Williams and Williams 1980).

Relict dace, which I maintained in laboratory aquaria, readily fed on commercial dry trout feed. They would rarely feed on the surface, but would ingest the food mid-water as it sank or feed on the bottom. On a couple of occasions large numbers of cultured *Daphnia schodleri* were introduced into the aquarium containing relict dace. All of the fish developed a feeding frenzy-voraciously consuming the zooplankton until none remained. The feeding on live *Daphnia* was much more intense than for the dry fish food.

Behavior and Activity

Hubbs et al. (1974) characterize relict dace as a very secretive species, more so than any other western species. It is especially retiring during cold periods. In its natural environment it is a mid-water swimmer and is seldom observed at the surface or resting on the bottom. However, if alarmed it will dive into the soft mud substrate or the submerged vegetation. These habits were particularly striking in the open marshes of Ruby Lake, where Hubbs et al. (1974) noted it may be an escape response from the abundant waterfowl. The relict dace I maintained in the laboratory would spend most of their time hiding behind rocks, if available. They were also frequently observed swimming mid-water, but rarely near the surface.

Aquatic vegetation is an important aspect of relict dace habitat. Heavy growths of *Chara, Nasturtium,* filamentous algae, *Potamogeton, Utricularia,* rush, bur-reed, and moss are characteristic of relict dace habitat (Hubbs et al. 1974). Personnel from NDOW and BLM (1980) also recorded *Nasturtium, Chara, Carex,* mares tail, Junea, bull and spiked rush, *Rorippa,* moss, and filamentous algae in relict dace habitats. Although I didn't conduct any vegetation analysis, observations indicated that water cress *(Nasturtium)* may be the most characteristic plant in undisturbed relict dace habitats. Dense aquatic vegetation provides important cover for relict dace.

Relict dace in Phalan Spring, where temperature was constant (≈20 C) throughout the day, exhibited an interesting diel activity pattern ***(Figure 9)***. Catch rates were very high between 1200 and 1500 hours, associated with high levels of dissolved oxygen (≈7 mg/ℓ). Between 1500 and 1800 hours DO levels decreased to below 5 mg/ℓ at the spring head and remained low throughout the night—this was apparently due to cesation of photosynthesis. The downstream station exhibited DO levels ≈1 mg/ℓ higher, apparently due to aeration. Corresponding to the decreases in DO concentration, the activity of relict dace, as indicated by minnow trap catches, dramatically declined and remained low throughout the night. Between 0900 and 1200 hours the DO at the downstream station returned to a concentration >7 mg/ℓ; however at the spring head DO remained low—apparently photosynthesis was not yet evolving oxygen at a high enough rate to compensate for the inflow of low DO groundwater. I expected the catch rate of dace to increase corresponding to increased DO levels at the downstream station, but it remained low. I believe the dace avoided the traps during the daylight hours ofthe second day (0600-1200) due to the continued disturbance caused by sampling. However, these DO—activity relationships illustrate that in a constant temperature environment relict dace may respond to oxygen levels (as well as photoperiod) as a primary environmental stimulus. Killifishes *(Crenichthys)* in eastern Nevada thermal springs responded to both darkness and low DO levels by reducing their activity (Hubbs et al. 1967).

Although DO levels of 4.5-5.8 mg/ℓ were apparently sufficient to depress activity, the fish did not show any overt symptoms of stress. Relict dace maintained in the laboratory (Atwood Ranch population) showed sub-lethal stress when DO levels declined to

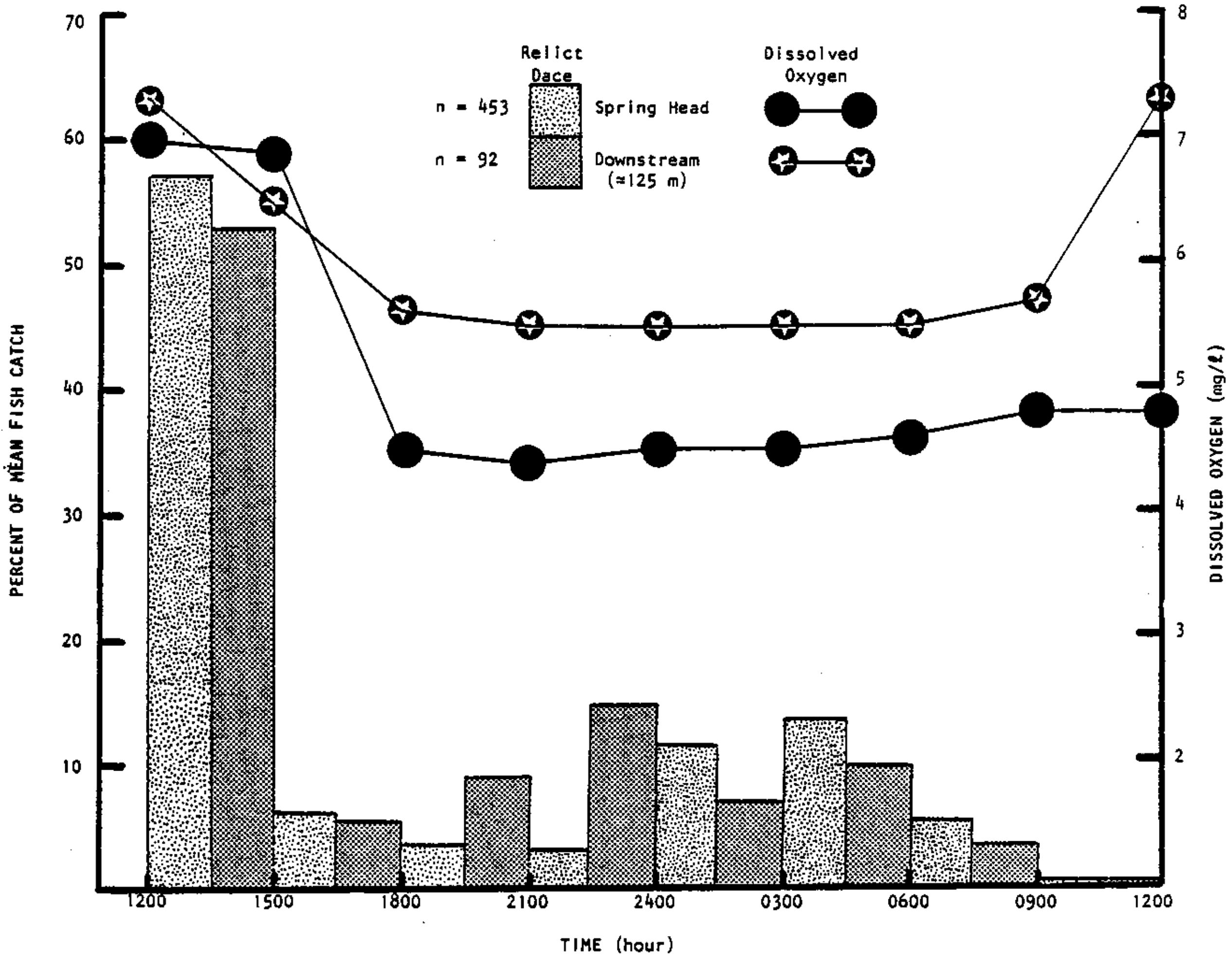

Figure 9. Diel activity of relict dace (catch/minnow trap) in relation to dissolved oxygen at the headwaters of Phalan Spring, Goshute Valley on Febraury 26-27, 1981.

1.4 mg/ℓ. The fish stayed at the surface, gulped air, ventilated rapidly, became lethargic, and would not respond to stimuli; however, the fish recovered when DO levels were returned to normal.

Mortality

The mortality rate of a fish population is an important parameter for the evaluation of its population dynamics. The decreasing number of fish to the right of the modal length in the length-frequency distribution of a population is related to the mortality rate, i.e., there are progressively fewer fish in older age classes.

Relict dace are subjected to a variety of natural and artificial causes of mortality, some have been alluded to in previous sections. Natural causes of death include catostrophic occurrences, seasonal desiccation of habitats, insect predation, canabilism, bird predation (waterfowl, gulls, herons, etc.), mammal predation (including harvest by humans for food), paricitism and disease, adverse environmental conditions, and ultimately old age (senility). Since relict dace have few natural enemies, senility may be an important cause of death under natural conditions. Artificial causes of death include various methods of habitat degredation and introductions of exotic diseases, competitors, and predators. These factors are discussed in other sections.

Two interesting causes of mortality of relict dace were noted in this study. A large predaceous bug, *Lethocerus angustipes*, was observed to capture and kill a relict dace in Quilici Spring. The Atwood Ranch Spring population is heavily infested by *(Neodiplostomum cuticola* Ciurea). The metacercariae of this worm (known as *Neascus cuticola* von Nordmann) give rise to small black-pigmented nodules on the skin, trunk musculature, and fins. The black patches on the dermis are caused by the concentration of melanophores which encapsulate the metacercariae. The worm completes its life cycle during its sexual maturity in an aquatic bird. It is not known if this infestation actually causes death, but it may be a debilitating factor for the population. Identification and information on this disease was provided by Marvin Burgoyne, Nevada Department of Wildlife.

SUMMARY AND CONCLUSIONS

Relict dace (Family: *Cyprinidae;* Genus: *Relictus;* Species: *solitarius)* was described by Hubbs and Miller (1972) from research dating back to 1934. It was once the most abundant species in the north-central Great Basin; however in recent times numerous populations have been extirpated-particularly in the Ruby Marshes, northern Goshute Valley, the Grass Springs complex of Steptoe Valley, and southern Butte Valley. Although some populations still occur in high numbers (e.g. Odgers Creek, Butte Valley), and the species as a whole is in no immediate danger of extinction, consideration should be given to maintaining the diversity of the species' gene pool. Continued degradation of relict dace habitats and losses of populations seems inconsistant with the fact that the species has recently been taken off the State of Nevada protected species list.

Before the advent of European culture, relict dace was the sole fish species within its range. It does not successfully compete with exotic species. Introductions of such species as largemouth bass, various trouts *(Salmo* and *Salvelinus)*, Sacramento perch, Utah chub, goldfish, and carp generally spell doom for the native relict dace.

Three general types of habitats currently exist for the species: (1) warm thermal springs (2) non-thermal springs and creeks (3) ponds and intermittant lakes. Vast spring-slough complexes (e.g. Ruby Marshes and Duck Creek Slough), which probably supported the most abundant populations, are no longer available as relict dace habitat.

The life history of various populations of relict dace probably depends on the type of habitat. Since most fish are extremely opportunistic, its diet probably reflects the abundance and availability of food organisms in a specific habitat. Stomach contents indicated that relict dace feed on various organisms including insects, amphipods, ostracods, and leeches. In the laboratory, relict dace readily feed on commercial trout feed, and voraciously attack live zooplankton.

In non-thermal habitats with pronounced seasonal environmental variations, it is likely that growth rings on scales, fin rays, or otoliths may be used to interpret age composition; but in relatively constant-temperature environments this technique would be inappropriate. However, size composition (e.g., length-frequency) gives an indication of the age structure, even in thermal habitats.

The reproductive strategy of the species is probably also dependant on the thermal regime; i.e., seasonal in non-thermal habitats and protracted (perhaps year-long) in thermal springs. Gravid females were sampled from the Narciss Spring, Ruby Valley during the fall season.

In one thermal spring (headwaters of Phalan) temperature was constant on a diel basis during mid-winter. Oxygen dynamics occurred however, and it is likely the DO levels (as well as light periods) have pronounced effects on the fishes diel activity and behavioral patterns.

The median thermal tolerance limit (96-hr TL_{50}) for a sample of Butte Valley (Atwood Ranch Spring) relict dace was 30.6 C. Relict dace tolerated much higher levels of salinity (>11,000 mg/ℓ TDS) than are found in their present habitats. A synergistic temperature-salinity effect was observed; i.e., interactions between temperature and salinity resulted in a lower lethal level than for either singular effect.

MANAGEMENT AND RESEARCH RECOMMENDATIONS

Hubbs et al. (1974) were relatively optimistic about the saftey of relict dace from extinction; the only "catastrophic depletion" they documented was in the Ruby Valley. They recommended:

> "...it would be preferable to retain separately representative stocks of both Ruby and Butte valleys (and even from Lake Franklin and Lake Gale divisions of Butte Valley). It would also serve science and conservation if sanctuaries could be built and maintained for the Johnson Ranch, Phalan Ranch, and above-Currie stocks of the Lake Waring basin, and for at least one, preferably several, stocks of *Relictus* in the basin of pluvial Lake Steptoe."

It seems ironic that in less than a decade since these recommendations were published, several of the stocks which Hubbs et al. (1974) singled out for conservation have apparently been eliminated; specifically: all the Lake Gale populations of Butte Valley, the above-Currie and (probably) the Johnson Ranch stocks of Lake Waring, and most of the Lake Steptoe (e.g. Grass Springs and Duck Creek Slough) stocks.

In light of the continued extirpation of relict dace populations I recommend a minimum of sanctuaries be established: 1) in Ruby Valley, perhaps North-east spring 2) in the lone remaining representative of Lake Waring, i.e., the headwaters of Phalan Spring, and 3) a representative of Lake Steptoe, perhaps the relatively unmolested springs on the Cordano Ranch.

It should be verified whether or not the Johnson Ranch (now Big Springs Ranch) habitats contain relict dace. The present managers of this ranch refused access to Hardy (1980) and myself to sample the springs, although I was allowed to look at the main spring and did not observe any fish. The attitude of the ranch foreman was that they didn't want any relict dace in the spring because it might interfere with their unrestricted use of the water. I believe ranchers who try to coexist with the species should not be unduly restricted in their use of water because they have maintained the endemic fish population compared to the less-progressive rancher who would eliminate the native fish in order to avoid the problem.

In reality the maintenance of the endemic fish population need not interfere with the agricultural use of the water as long as a relatively small area of the headwaters of a spring is retained as a sanctuary. The most detrimental practice is to dam up the springs into a large reservoir and introduce an exotic predatory species such as largemouth bass.

This study just scratched the surface on the ecology of relict dace. Further research is necessary to have an in-depth understanding of this relict genus and species; I recommend:

(1) Detailed food habits and bioenergetics in various habitats.

(2) Reproductive biology, including: age-specific fecundity, factors controlling spawning periods, and environmental requirements of eggs and larvae.

(3) More detailed research on the environmental requirements of juveniles and adults, e.g., lethal and sub-lethal effects.

(4) Population dynamics of the species as a function of environmental characteristics.

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APPENDIX I

GREAT BASIN DESERT FISHES
A Selected Bibliography

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November 1981

FORWARD

Three publications contain the most comprehensive literature reviews on Nevadan Great Basin desert fishes; namely, *Fishes and Fisheries of Nevada* (La Rivers 1962), *Hydrographic History and Relict Fishes of the North-central Great Basin* (Hubbs, Miller, and Hubbs 1974) and *Fishes and Aquatic Resources Death Valley System - A Bibliography 1878-1976* (Miller, Soltz, and Sanchez 1977). Over half of the citations listed in this bibliography are found in the latter publication; therefore, as acknowledgement, a symbol (‡) is placed next to each reference derived from this source. In addition, a star (★) denotes documents which were acquired during this research.

In general, I selected primarily journal publications for inclusion in this bibliography; and omitted obscure research reports, reports which duplicated published papers, and publications of "popular", non-technical interest. The purpose of these criteria was to provide a comprehensive but concise research tool with a minimum of redundancy.

The publication by Deacon et al. (1979) is very important since it lists fish species in North America which are Endangered, Threatened, or of Special Concern; a large proportion of these fish are endemic to the Great Basin of Nevada. Three other publications represent significant contributions to the biology of desert fishes in general, i.e., Deacon and Minckley (1974), Sotlz and Naiman (1978), and Naiman and Soltz, editors. (1981).

The bibliography is a product of research conducted on the relict dace *(Relictus solitarius)* during 1980-1981. To date the published literature on this species is sparse; references include: Hubbs and Miller (1948, 1970, 1972), Hubbs, Miller and Hubbs (1974), Smith (1978), Deacon et al. (1979), Hardy (1979), Lugaski (1980), and USDAF (1980). This work was funded by the Desert Research Institute Project Assignment Committee, Dr. Joy Leland, chairman.

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