

**NATURAL HISTORY AND ECOLOGY OF
THE CALIFORNIA RED-LEGGED FROG
AND BULLFROG AT THE WATERFOWL
PONDS, VANDENBERG AIR FORCE BASE,
CALIFORNIA**

12 November 2000

Prepared for
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Vandenberg AFB, California
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PREFACE

This document is the first in a series resulting from a cooperative research project between the U. S. Air Force, the Biological Resources Division (BRD) of the U. S. Geological Survey, and the University of California, Santa Barbara (1996 - 1998), and the U. S. Air Force and the Santa Barbara Museum of Natural History (1999 - 2000). Funding was provided by the U. S. Air Force, and BRD contributed research equipment and materials. All handling of California red-legged frogs was authorized under U. S. Fish and Wildlife Service Endangered Species Subpermit BRDPBS-2, and California Department of Fish and Game Scientific Collecting Permit Numbers 6954, 803050-01, 803053-01, 803087-05.

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SUMMARY

This document describes the results of studies on the California red-legged frog (*Rana aurora draytonii*), which were conducted at the Waterfowl Natural Resources Area (Waterfowl Ponds), Vandenberg Air Force Base (VAFB). The ponds were created for the purpose of providing habitat for migrating and resident waterfowl, as well as opportunities for wildlife viewing. The California red-legged frog (RLF), a federally threatened species, naturally colonized the ponds. The bullfrog (*Rana catesbeiana*), an introduced predator of the red-legged frog, invaded the site shortly thereafter. Management of the site will require provisions for the California red-legged frog. The present study was undertaken to obtain data upon which to base management decisions.

Colonization by the RLF was first observed in May 1996. A population estimate derived from mark-recapture data gathered between 1996 and 1999 gave the estimated number of subadult and adult RLF present to be 402, with the upper confidence limit for 1998-1999 at 643 frogs. Visual survey data was used to estimate the total population size at approximately 872 frogs in 2000. The population of RLF at the Waterfowl Ponds can be considered to be quite large.

Juvenile RLFs have been produced annually from 1996 through 2000. Demography data suggest that some juveniles survive to adulthood. There was no deficiency in any size class of frogs over the period of the study. Both male and female frogs which were 57-90 mm snout-urostyle length (SUL) in winter grew to > 90 mm SUL by the following fall.

Breeding choruses took place between November and April. Of the four ponds, Pond 1 (see Figure 2) was the most important for breeding. Pond 1 had the highest number of calling males and a high value for egg masses. In years when Pond 2 retained water throughout the summer, it also was an important site for breeding. Metamorphs were produced earlier in the season at Pond 2 in comparison to Ponds 4 and 5. Breeding microhabitat was relatively shallow water at the margins of the ponds, with low to moderate vegetative cover by young or dead cattails, sedge, shrubs, dead annual plants, and submergent macrophytes. Metamorphs selected for warm water at the shallow pond margins during the day. During the non-breeding season, adult frogs were most often seen near the boundary between open water and dense emergent vegetation, and were distributed evenly throughout each pond.

Bullfrogs invaded the Waterfowl Ponds on at least two separate occasions. The timing of bullfrog invasions appears to correspond with late-season rainfall. Bullfrogs were found almost exclusively in Pond 4. Analysis of water temperatures revealed that Pond 4 was warmer than Pond 5 during the bullfrog breeding season. Surface water temperature in Pond 4 was increased

by the presence of pondweed (*Potamogeton* sp.). A bullfrog egg mass that was found in Pond 4 was laid in pondweed, and the water temperature at the egg mass was greater than that of the ambient surface water temperature. No bullfrog tadpoles or metamorphs have been detected at the Waterfowl Ponds. The maximum number of bullfrogs seen during any one survey was 8. The number of bullfrogs has stayed about the same from the time of the second invasion (summer 1998) until summer 2000. Water temperatures measured at Pond 4 were about the same as those measured at another pond at VAFB which also has relatively low densities of bullfrogs, and were lower than those measured at two ponds that have high densities of bullfrogs.

Methods suggested to increase the opportunity for wildlife viewing at the Waterfowl Ponds and would have negligible or positive effects on the RLF include the creation of small openings in the vegetation, the installation of floating piers, and the rehabilitation of two currently unused pond basins at the site. Present management practices could be modified to benefit sensitive species, such as decreasing water fluctuations in the ponds during critical periods for RLF reproduction, no mowing when southwestern pond turtles (*Clemmys marmorata pallida*) are on the trails, and covering the water gates to prevent RLFs from being trapped. Future development of the site should include plans to curb human access to the pond margins, and to discourage the likelihood of fish introduction by visitors. Monitoring of the RLF and bullfrog populations should be continued. If bullfrogs are found to reproduce successfully, or if their numbers increase, management of the bullfrog population by drying the ponds in the fall should be employed. Further research is needed on the microhabitat use and movement patterns of juvenile RLF during the first winter following transformation.

CONTENTS

PREFACE.....	i
SUMMARY.....	ii
CONTENTS.....	iv
LIST OF TABLES.....	vi
LIST OF FIGURES.....	vi
1.0 INTRODUCTION.....	1
1.1 Site background.....	1
1.1.1 Location.....	1
1.1.2 Site history.....	2
1.2 California red-legged frog.....	5
1.2.1 Species description.....	5
1.2.2 Microhabitat associations and movement.....	6
1.2.3 Source of colonists.....	9
2.0 METHODS.....	10
2.1 Habitat mapping.....	10
2.2 Population trends.....	11
2.2.1 Capture and handling.....	11
2.2.1.1 PIT tagging.....	11
2.2.1.2 Toe clipping.....	12
2.2.1.3 Population size estimate.....	12
2.2.2 Visual survey.....	14
2.2.3 Survey effort.....	14
2.2.4 Demography.....	15
2.2.5 Individual growth.....	16
2.3 Reproduction.....	17
2.3.1 Calling.....	17
2.3.2 Egg masses.....	17
2.3.3 Metamorphosis.....	18
2.4 Bullfrogs.....	20
2.4.1 Relationship with rainfall.....	20
2.4.2 Relationship with water temperature.....	20
2.5 Species List.....	22
3.0 RESULTS AND DISCUSSION.....	23
3.1 Habitat.....	23
3.1.1 Distribution of captures.....	23
3.1.2 Changes in habitat.....	25

CONTENTS (Continued)

3.2 Population trends.....	25
3.2.1 Mark-recapture studies.....	25
3.2.2 Visual survey.....	26
3.2.3 Demography.....	27
3.2.4 Individual growth.....	28
3.3 Reproduction.....	29
3.3.1 Calling.....	29
3.3.2 Egg masses.....	30
3.3.3 Metamorphosis.....	32
3.4 Bullfrogs.....	34
3.4.1 Relationship with rainfall.....	35
3.4.2 Relationship with water temperature.....	36
3.5 Species List.....	38
4.0 RECOMMENDATIONS FOR MANAGEMENT.....	39
4.1 Openings in the vegetation.....	39
4.2 Floating piers.....	41
4.3 Rehabilitate the other basins.....	42
4.4 Restrict excessive development.....	43
4.5 Decrease water fluctuations at critical periods.....	43
4.6 No mowing during turtle season.....	44
4.7 Cover water gates.....	44
4.8 Future monitoring.....	44
5.0 ACKNOWLEDGMENTS.....	46
6.0 LITERATURE CITED.....	47
7.0 PERSONAL COMMUNICATION.....	53

1.0 INTRODUCTION

TABLES

1. Proportion of captures marked.....	54
2. Population estimate from mark-recapture data.....	55
3. Visual survey data for adults and subadults.....	56
4. Visual survey data for metamorphs.....	57
5. History of bullfrog sightings.....	58
6. Pond water temperatures.....	59
7. Species list.....	60

FIGURES

1. Area map.....	61
2. Project site map.....	62
3. Pond 1 picture.....	63
4. Pond 2 picture.....	63
5. Pond 4 picture.....	64
6. Pond 5 picture.....	64
7. California red-legged frog pictures.....	65
8. Pond 1 map.....	66
9. Pond 4 maps.....	67
10. Pond 5 maps.....	68
11. Demography of frogs by year.....	69
12. Growth of female frogs.....	70
13. Growth of male frogs.....	71
14. Mass of frogs by length, in winter vs. non-winter.....	72
15. Number of calling frogs per month.....	73
16. Number of calling frogs per pond.....	74
17. Calling site picture.....	75
18. Number of egg masses per pond.....	76
19. Oviposition site in Pond 1 picture.....	77
20. Oviposition sites in Pond 4 picture.....	77
21. Ratio of metamorphs to tadpoles trapped per pond.....	78
22. Monthly precipitation.....	79
23. Dead cattail mat picture.....	82
24. Dense cattail clump and open water picture.....	82
25. Frog island picture.....	83

1.0 INTRODUCTION

This document describes the results of studies on the California red-legged frog (*Rana aurora draytonii*), which were conducted at the Waterfowl Natural Resources Area (Waterfowl Ponds), Vandenberg Air Force Base (VAFB). The ponds were created for the purpose of providing habitat for migrating and resident waterfowl, as well as opportunities for wildlife viewing. The California red-legged frog, a federally threatened species, naturally colonized the ponds. The bullfrog (*Rana catesbeiana*), an introduced predator of the red-legged frog, invaded the site shortly thereafter. Management of the site will require provisions for the California red-legged frog. The present study was undertaken to obtain data upon which to base management decisions.

This report is the first in a series resulting from research which was conducted between winter 1996 and summer 2000. A subsequent document will detail the results from a concurrent radio-tracking study of California red-legged frogs at the Waterfowl Ponds. A third report will provide water quality analyses from the Waterfowl Ponds as well as other sites at VAFB. This document details the results of population monitoring, observations of reproduction, and bullfrog invasion with respect to particular aspects of the habitat. Recommendations are given for management of the Waterfowl Ponds.

1.1 Site Background

1.1.1 Location

Vandenberg Air Force Base is located in northwestern Santa Barbara County, California. The Waterfowl Ponds are located on North Base, between the Santa Ynez River and Terra Road (Figure 1). This area is in the floodplain of the river, but due to the construction of dams in the upper reaches of the

river and alterations in the channel morphology downstream of Lompoc (i.e., natural and artificial levees, diversion of tributaries) this area rarely receives flood flows.

The soil in the vicinity of the Waterfowl Ponds is Marina sand, and the topography is rolling hills and dissected terraces (McElligott 1989). To the west and south of the Waterfowl Ponds is a riparian woodland, comprised mainly of willow (*Salix* sp.). On the north edge of the site is a slough that is vegetated mainly by willow, and this area floods during years with exceptionally high precipitation. To the east is an agricultural field. The vegetation surrounding the ponds is mainly ruderal and is dominated by coyote brush (*Baccharis pilularis consanguinea*) and non-native weedy species (McElligott 1989).

1.1.2 Site History

The Waterfowl Ponds site was a wastewater treatment facility in the 1970s. Originally, there were 6 main percolation ponds, at least 6 auxiliary basins, and a system of earthen berms (Figure 2). While the facility was in operation, the ponds attracted a variety of waterfowl and it was a popular site for wildlife viewing (McElligott 1989). The Youth Conservation Corps and the U. S. Navy Seabees performed habitat enhancement projects in 1977 and 1978 (McElligott 1989). The facility was closed in 1979 when VAFB connected to the Lompoc wastewater treatment plant. Thereafter the area became overgrown with ruderal and facultative wetland species (McElligott 1989). It is likely that some of the basins held rainwater for a short time during the spring. McElligott (1989) stated that Pacific treefrogs (*Hyla regilla*) were observed at the site prior to the rehabilitation effort. One of the auxiliary basins which was not rehabilitated continues to retain water during winters with average to high levels of rainfall (personal observation).

The La Purisima Audubon Society (LPAS), VAFB, and the California Coastal Conservancy formed a partnership to rehabilitate the site. VAFB contributed labor for the construction effort, the Coastal Conservancy provided a grant of approximately \$200,000, and LPAS managed the project (Sehgal, personal communication). A controlled burn was conducted to remove vegetation in late 1992 (U. S. Air Force 1993). In the spring and summer of 1993, the six main pond basins were re-excavated to approximately 5 feet deep (Sehgal, personal communication). The sides of the basins were graded to a gradual slope. Due to construction costs which were higher than anticipated, the project was downsized to 4 of the 6 basins (1, 2, 4, & 5; see Figure 2). A bentonite clay liner and a 12" layer of topsoil were compacted into the bottoms of the 4 basins (Sehgal, personal communication). The only source of seeds that were introduced during the rehabilitation project came from the layer of topsoil, which had been retained from the re-excavation of the basins. An overhead powerline was installed to bring electricity to 2 3-horsepower well pumps (McElligott 1989, U. S. Air Force 1993). The pumps produce 350 and 125 gallons/minute from 2 wells at the site (Sehgal, personal communication). The water is piped underground to the southwestern ends of Ponds 4 and 5 (see Figure 2). When these ponds are at capacity, water flows through watergates to Ponds 1 and 2 (e.g., Pond 4 drains to 1, and Pond 5 drains to 2). Trails encircle each of the 6 ponds, and connect the site to Terra Road and the Santa Ynez River. An observation tower was erected at the midpoint between the 4 rehabilitated basins. The total area of the 4 ponds is approximately 21 acres (U. S. Air Force 1993).

The pumps were first put into operation in December 1993 (U. S. Air Force 1993), but were unable to completely fill the ponds. When I visited the site in late May 1995, the pumps were not functioning properly and only Pond 5 had a little standing water. By this time cattails (*Typha* sp.) had begun growing in Pond 1, and the other basins were mostly bare ground. The pumps were repaired, and on my next visit in late May 1996 the water levels were at

"normal". Normal levels for summer and fall were such that Ponds 4 and 5 were at capacity, Pond 1 was at or below half-capacity, and Pond 2 was dry or nearly-dry. In the winter and spring, Pond 1 would fill to near-capacity and Pond 2 to half-capacity. By October 1996, aquatic and emergent vegetation was well-established in all of the basins, and cattails were present in dense stands covering almost 50% of Pond 5. Coverage by dense vegetation increased from that time onward. Photographs of each of the ponds taken in 1997 are given in Figures 3 through 6. By 1999, it was not possible to see through the vegetation to open water at Ponds 1, 4, and 5. A decision was reached between LPAS and VAFB to stage a controlled burn at Pond 1. In preparation, dense coastal sage scrub was manually removed from around the perimeter of the pond. The burn was conducted in late-fall 1999 when the cattails were dead and dry. The burn effort was effective at removing cattails to the water level, as well as increasing visibility from the perimeter, but by early May 2000 young cattails had re-established throughout the pond.

The Waterfowl Ponds would be more accurately described as "artificial wetlands". The presence of water in the ponds in summer and fall is completely dependent on pumping water into the basins. When the pumps malfunctioned during the summer, the water level in all of the ponds dropped dramatically within a few weeks. Even though the habitat rehabilitation project can be praised for successfully creating California red-legged frog habitat, it is not a self-sustainable system.

I first observed California red-legged frogs at the Waterfowl Ponds on 31 May 1996, and began studies of the frog in October 1996. The purpose of these studies was to obtain background data on the ecology of the California red-legged frog which could be incorporated into VAFB's management plans for the site. These plans will balance the desire to manage the vegetation at the site to permit wildlife viewing with the need to prevent take of the California

red-legged frog as protected under the federal Endangered Species, National Environmental Quality, and California Environmental Quality Acts.

1.2 California Red-legged Frog

1.2.1 Species Description

The California red-legged frog (*Rana aurora draytonii*) is the largest native frog in the state, with a body length up to 130 millimeters (Stebbins 1985). The adults are characterized by reddish coloration on the abdomen and hind legs, prominent dorsolateral folds, and a tympanic membrane which is smaller in diameter than the eye (Storer 1925, Figure 7).

This species occurs in the coast ranges of California from Point Reyes National Seashore to Ventura County (Storer 1925, Stebbins 1985, Jennings and Hayes 1994). Historically it was also found in the Central Valley, Sierra Nevada foothills, coastal southern California, and northern Baja California, but almost all of these populations are now extinct (Stebbins 1985, Jennings and Hayes 1994). It is presently found at elevations ranging from sea level to 803 meters (2650 feet) (Jennings and Hayes 1994, Barry 1999). The northern red-legged frog (*Rana aurora aurora*) ranges from British Columbia to northern California (Stebbins 1985). The systematic relationship between these taxa is incompletely understood (Hayes and Kremples 1986, Jennings et al. 1992). California red-legged frogs occur in streams, ponds, lakes, and reservoirs (Storer 1925, McKeown 1974, Stebbins 1985). They are found primarily at sites with still or slow-moving water that are permanent or semi-permanent (Storer 1925, Jennings 1988, Hayes and Jennings 1989).

The California red-legged frog is listed as threatened under the Endangered Species Act (U. S. Fish and Wildlife Service 1996). In the late 1800s, populations of the California red-legged frog declined dramatically due to

overharvest for human consumption (Jennings and Hayes 1985, Stebbins 1985). Over the past 100 years, the frog's habitat has been drastically altered or eliminated due to urbanization, agricultural development, flood control practices, the creation of reservoirs, and livestock grazing (Hayes and Jennings 1986, 1989, Jennings 1988, Jennings et al. 1992). Even in protected habitats this species is negatively affected and may be excluded by introduced predators including bullfrogs (*Rana catesbeiana*), fish (Moyle 1973, Hayes and Jennings 1986, 1989), and crayfish (Jennings et al. 1992). Degradation of aquatic habitats may result in conditions that are not only less suitable for California red-legged frogs, but which are favored by these introduced species (Hayes and Jennings 1986, 1989, Jennings 1988, Jennings et al. 1992). Isolation of California red-legged frog populations due to habitat fragmentation and the presence of introduced predators may prevent recolonization following local extinctions (Jennings et al. 1992).

1.2.2 Microhabitat Associations and Movement

Habitat of adult California red-legged frogs has been characterized as having dense shoreline and emergent vegetation (Storer 1925, Jennings 1988, Hayes and Jennings 1989, Jennings and Hayes 1990, Rathbun et al. 1993, Christopher 1996b), and water at least 70 cm deep (Hayes and Jennings 1989, Christopher 1997b). The type of emergent vegetation appears to affect frog abundance, presumably because differences in structure relate to differences in protection from predators, suitability for oviposition sites, and for larval stages (Jennings and Hayes 1990). Cook (1997) provides an intensive study of microhabitat use by the California red-legged frog at a marsh in northern California. He found that during the non-breeding season, the frog was most often found in dense emergent vegetation (especially smartweed, *Polygonum hydropiperoides*) and was not often found in open water. Christopher (1997b) also found that California red-legged frogs selected for areas with dense cattails and sedges (*Carex* sp.), and selected against open water.

In Cook's (1997) marsh, egg masses were attached mainly to dead spikerush (*Eleocharis macrostachys*) mats that were laying horizontally near the water's surface. Some egg masses were attached to cattails, but none were attached to bulrushes (*Scirpus* sp.) even though bulrush was the dominant vegetation at the marsh. At VAFB, California red-legged frog egg masses have been found laid on horizontally-oriented dead cattail mats, floating mats of aquatic buttercup (*Ranunculus* sp.), and bent bulrush stems (Christopher 1997b, personal observation). However, other authors report that California red-legged frogs typically attach their egg masses to a vertically-oriented vegetative brace such as a cattail stalk or bulrush stem (Jennings and Hayes 1989, Jennings et al. 1992). Christopher (1997b) found that 50% of California red-legged frog egg masses which were attached to vertically-oriented bulrush stems were partially desiccated due to stranding out of water. Jennings and Hayes (1990) also report this situation. Stranding could be due to fluctuating water levels or quick growth of the stems. Cook (1997) found the egg masses in relatively shallow water (mean 32.8 cm). At VAFB, 84% of egg masses were laid at depths ranging from 20 to 50 cm, and the mean water depth at egg masses for cattail-dominated ponds (34 cm) was slightly lower than for bulrush-dominated ponds (40 cm) (Christopher 1997b).

Since most mortality probably occurs between hatching and metamorphosis (Jennings et al. 1992), habitat of the tadpoles is especially important. The survivorship rate for this stage has been estimated at less than 1% (Jennings et al. 1992) and 1.9% (Cook 1997). California red-legged frog tadpoles are mainly benthic and spend most of their time in emergent vegetation (Christopher 1997b). Larvae are thought to be algal grazers, but the foraging ecology of this subspecies remains unstudied (Jennings et al. 1992). Eutrophic systems such as marshes probably have an abundance of food resources for red-legged frog tadpoles and therefore competition is probably not a significant source of mortality (Calef 1973, Cook 1997). Most mortality of larvae can probably attributed to predation (Calef 1973, Licht 1974). A wide

variety of organisms are known to prey upon ranid tadpoles, including aquatic invertebrates, snakes, salamanders, crayfish, fish, and frogs (Fox 1952, Calef 1973, Arnold and Wassersug 1978, Stuart and Painter 1993, Rowe et al. 1994, Werner and McPeck 1994, Axelsson et al. 1997, Kiesecker and Blaustein 1997). The presence and complexity of vegetation can decrease predation rates on tadpoles by increasing refugia (Crowder and Cooper 1982, Gillinsky 1984) and decreasing predator efficiency (Ware 1973, Crowder and Cooper 1982, Persson and Eklov 1995). Since smaller tadpoles are more vulnerable than large tadpoles to many predators (Heyer et al. 1975, Semlitsch and Gibbons 1988, Fauth 1990), shorter larval periods may increase survivorship (Wilbur 1980, Semlitsch and Gibbons 1988). Growth rates of tadpoles have been shown to increase with water temperature (Calef 1973).

Following metamorphosis, California red-legged frogs are often seen basking during the day on floating and submerged vegetation, where there is a warm surface layer of water (Hayes and Tennant 1985). Juvenile frogs may increase their growth rates through selection of warmer habitats (Lillywhite et al. 1973). Christopher (1997b) found that post-metamorphs are most often observed in relatively shallow water (mean 30 cm, $n=199$) and in areas with little or no vegetative cover. Recently-metamorphosed northern red-legged frogs first gathered on the shore and then moved into woodland habitats (Calef 1973, Twedt 1993). Dispersal and terrestrial habitat use by juvenile California red-legged frogs has not been studied.

Adult California red-legged frogs may be found far from water during winter rain storms (Storer 1925, Stebbins 1985, Rathbun et al. 1993). While in terrestrial riparian habitats they take cover under dense vegetation (Rathbun et al. 1993; Christopher, unpublished data). Individuals have also been found concealed in pockets or animal burrows in undercut banks during high water flow in streams and rivers (Jennings et al. 1992). Adults occupy breeding sites in late fall and winter, and move to foraging habitat in summer and early fall

(Jennings et al. 1992). Individuals are also known to move substantial distances in response to seasonal changes in habitat quality (Jennings and Hayes 1989) such as habitat desiccation.

1.2.3 Source of Colonists

It is not known whether the California red-legged frog inhabited the Waterfowl Ponds site when it was in use as a wastewater treatment facility. This species is present in relatively high densities at the wastewater ponds adjacent to the Space Launch Complex 6 on South Base (Christopher 1996a, 1997a, 2000). During the period following the Terra Road plant's closure and prior to habitat rehabilitation, it is possible that some frogs may have temporarily occupied the site during relatively wet years.

The nearest locality from which the California red-legged frog has been documented is the lower Santa Ynez River (Coulombe and Mahrtdt 1976, Hunt 1990, Christopher 1996b). Frogs inhabiting the river probably would not be considered a "source population" because numbers are quite low, and the abundance and diversity of introduced aquatic predator species are likely to drastically reduce or eliminate the frog's reproductive effort in most years (Christopher 1996b, Swift et al. 1997). The California red-legged frog is present at a few other ponds and tributaries in the Santa Ynez River floodplain on VAFB (Christopher 1995, 1996b). It is possible that the river and adjacent riparian woodland are a corridor for movement between these sites.

2.0 METHODS

The primary focus of the 1996 - 1998 California red-legged frog studies at the Waterfowl Ponds was radio tracking frogs to examine movement patterns and habitat use. Methods were developed primarily for this project, and secondarily to allow for studies of population size, structure, and reproduction.

2.1 Habitat Mapping

Maps were drawn which show vegetation and water depth for Ponds 1, 4, and 5. The ponds were divided into 20 X 20 meter sections. Stakes were placed around the perimeter of the ponds at the boundaries of the sections using a measuring tape and compass. The stakes were approximately 5 meters from the water's edge. Light-reflective tape was attached to emergent vegetation on the inside of the pond and marked with section numbers. This allowed for the identification of the section number for each frog caught.

From top view, the waterline was drawn on graph paper in relation to the stake line. Vegetation type was indicated by color for each subsection of ⁴ 5 X ⁴ 5 meters (Figures 8 - 10). Water depths were measured perpendicular to the stake line.

The first set of maps was drawn in November 1996, and water depths were measured in December 1996. Because the vegetation progressively encroached on the open water, the maps were updated in April 1997, and finally in August 1997. The updated maps were drawn only for Ponds 4 and 5, since studies were discontinued in Pond 1. Water depth was updated in March 1997. No maps were prepared for Pond 2 since it was usually dry.

2.2 Population Trends

2.2.1 Capture and Handling

Between 1996 and 1999, California red-legged frogs were captured at night using a high-intensity focused-beam light (Wheat Cap Lamp, Koehler Manufacturing, Malborough, Massachusetts). Frogs were caught mainly by hand while wading, and occasionally a dip net and/or float tube were used. An attempt was made to catch every frog seen. Captured frogs were placed individually in 1-gallon resealable plastic bags. The inside of the bags was dampened with pond water, and the bags were inflated with sufficient air. Bags were marked with a unique number, and a flag with that number was tied at the point of capture. Frogs were held in the bags until each pond had been surveyed, which was usually less than 75 minutes. After a training period for USFWS-authorized field assistants, each pond was surveyed by one observer. At the completion of the first pass through the ponds, frogs were processed as described below. After frogs from one pond had been processed, the assistant returned them to the exact points of capture. Additional captures were made while returning the first batch of frogs. This process was repeated until no frogs remained above water.

2.2.1.1 PIT Tagging

Passive integrated transponder (PIT) tags (Destron Fearing Corporation, Boulder, Colorado) were used to give a unique mark to frogs (Camper and Dixon 1988, Heyer et al. 1994) which were > 60 mm snout-urostyle length (SUL). Each PIT tag has an electromagnetic coil and a microchip which are encased in glass. The external dimensions are 2 X 12 millimeters, and each weighs 0.05 grams. Each tag possesses a unique alphanumeric code that is read by generating a low-frequency electromagnetic signal with an external reader (Miniportable Reader, Destron Fearing Corporation, Boulder,

Colorado) held within a few centimeters of the tag. PIT tags and surgical equipment were sterilized using ethanol. The tags were inserted subcutaneously, anterior to the sacral hump, by making a V-shaped notch in the skin with a sharp pair of nail clippers. Tags were manipulated over the sacral hump, and positioned anterior to the urostyle on the dorsal surface. The skin incision healed within a few days, and recaptured frogs did not show any signs of infection resulting from this procedure.

2.2.1.2 Toe Clipping

All frogs that were marked with a PIT tag also received a toe clip (Rathbun et al. 1993). The distal tip of the forth (longest) digit on the right rear leg was clipped and retained in 95% ethanol. The toe tips were donated to Dr. H. Bradley Shaffer (University of California, Davis). Frogs <62 mm SUL, were marked only by clipping one toe on the left hind leg. The toe which was clipped indicated the pond in which the frog had been caught.

2.2.1.3 Population Size Estimate

Most methods to estimate population size from mark-recapture data require equal probability of capture between all individuals in the population (Pollock et al. 1990). This assumption is violated in most studies of animal populations (Carothers 1973, Seber 1973). Individuals may differ in capture probability due to age, sex, social status, and whether or not the individual has been captured previously (Pollock 1982). In the present study, there was a substantial decrease in the probability of capturing a frog which had previously been caught. When sampling was intensive, frogs quickly became "light shy" - they dove under water as soon as the light was shone on them. Even after a break in sampling for a period of several months, this response continued to affect capture success. After a one-year break in sampling, the frogs lost this response and would remain above water throughout

substantial amounts of physical disturbance (i.e., splashing and wave action due to float tube fins becoming entangled in pondweed, and the float tube coming within several centimeters of the frog). It is not known whether the frogs had "forgotten the threat" of capture, or if the majority of those present after one year were new individuals.

Burnham and Overton (1978, 1979) developed a heterogeneity model which assumes that capture probabilities vary among individuals but are constant over time. They developed a jackknife technique to derive a series of estimators of capture probabilities. The jackknife estimator is robust if many individuals are caught a relatively large number of times (Otis et al. 1978). I used Chao's (1987) method to estimate population size when capture probability is variable. This model is robust to low rates of recapture (i.e., most individuals caught ≤ 2 times). Chao's (1987) method is intended for use with closed populations. Pollock (1982) stated that the designation of open versus closed populations for these types of analyses was artificial. While data on immigration to the Waterfowl Ponds is not known, radio-tagged frogs were not found to emigrate from the site (Christopher, unpublished data).

I divided the capture data into three time intervals for analysis. The first interval covered 1996 and 1997, the second 1998 to 1999, and the third pooled data from 1996 through 1999. The first interval was very soon after the frog had colonized the site. The capture effort during the first interval was substantially greater than in 1998 and 1999. The third interval estimates the population size across all sampling periods. California red-legged frogs can live for more than four years. Only frogs > 60 mm SUL and those that were captured randomly (the capture was not the direct result of radio-tagging or having been trapped in a water gate) were included in the analysis.

2.2.2 Visual Survey

The total number of frogs seen per pond was noted during each survey. Frogs were broken into two size categories - adult/subadult (> 57 mm SUL) and metamorph (≤ 57 mm SUL). Using repeated visual surveys may be a better technique for assessing population trends under a long-term monitoring program in which the observers differ. In addition, this method can be performed with little cost, reduced effort, decreased disturbance to the frogs, and currently without the need for collecting permits. Even using the same observer(s) and methodology, the number of frogs detected can vary greatly between nights. Since the activity of the California red-legged frog varies seasonally, only data from surveys conducted between 1 June and 30 September were used, except for 1996 when the project had just begun and the surveys were conducted 14 October - 28 December. Late-summer and fall is probably the best time to conduct surveys for population monitoring because metamorphs are also readily detected at this time. The maximum number of frogs seen in one survey period (year) was compared across survey periods for each pond. Due to variation in the size of the survey area, the numbers of frogs seen is given relative to the size of the area surveyed. Estimates of the total number of frogs that potentially could have been encountered if the ponds were surveyed in entirety were derived (see Section 2.2.3).

2.2.3 Survey Effort

The areas surveyed and the number and timing of surveys varied based on the water levels, extent of impenetrable vegetation, and need to capture frogs for radio tagging. Ponds 1 and 2 were surveyed only a few times, and most of the effort was at Ponds 4 and 5. In 1996 and 1997, the inside edge of the emergent vegetation in Pond 4 could be surveyed by wading. At that time, there were also gaps in the perimeter band of vegetation which allowed access to parts of the shore. In 1998, frogs were captured only from the areas that

could be waded in Pond 4 (Sections 3 - 4 and 9 - 11; Figure 9) because it was difficult to catch frogs from float tubes. In 1999 and 2000 the focus shifted from catching frogs to counting them, and the inside perimeter of the emergent vegetation was searched using float tubes. Throughout 1996 and 1997, different areas of Pond 5 were surveyed each time. Usually Sections 10, 11, and 12 (Figure 10) were covered because these were the most productive areas for catching frogs. Less frequently surveyed were the open areas on the C side, the middle of the pond in Sections 6B through 8B, and a float tube was used for the middle of the pond in Sections 1 through 5. In 1998 only Sections 9 - 11 were searched in Pond 5. Section 9 became inaccessible, and only sections 10 and 11 were searched in 1999 and 2000. The pond maps allowed the calculation of the survey area.

Pond 4 was surveyed on 8 nights in 1996, and 16 nights in 1997. Pond 5 was surveyed on 7 nights in 1996, and 16 nights in 1997. Surveys became less frequent after the radio tracking study was terminated in March 1998. Surveys were conducted only from June through September in 1998, 1999 and 2000, and frogs were counted in 2000 without attempting to catch them. Ponds 4 and 5 were surveyed 2 - 5 times in 1998, 1999, and 2000.

2.2.4 Demography

Each frog that was captured as described in Section 2.2.1 was sexed, weighed and measured prior to release. Male California red-legged frogs were determined as possessing enlarged forelimbs and nuptial pads on their thumbs (Stebbins 1985). These features are not prominent in individuals less than about 70 mm SUL, especially when captured outside of breeding season. Misidentification of sex was known to occur a few times when small frogs were initially recorded as females, and when recaptured several months later it was apparent that they were males. It is unlikely that females would have

been misidentified as males. The sex of metamorphs could not be determined.

Frogs were weighed to the nearest 0.5 gram using Pesola spring scales. Frogs were weighed individually while in the resealable bags, and then the frog was removed and the bag was reweighed. The weight of the bag and the drops of pond water were subtracted from the total weight. Length was measured from the tip of the snout to the urostyle. Frogs were placed on a ruler, and gentle pressure was applied to relax and extend the body. From the stress of being caught, California red-legged frogs tend to "tense up" and contract their bodies by raising the sacrum. The accuracy of their length measurement depends on the ability to coerce them to lay flat against the ruler. For this reason, there is a degree of error associated with length measurements (Turner 1960; see Section 3.2.4).

Three different size groups were determined: metamorphs, small frogs, and large frogs. Metamorphs (< 57 mm SUL) were young-of-the year. The age of small frogs (57 - 90 mm SUL) cannot be determined without additional analysis such as skeletochronology (see Collins et al. 1996), but they were probably between 1 and 3 years old. Large frogs (> 90 mm SUL) were probably 2 or more years old. Growth of recaptured frogs (Section 3.2.4) indicated that male and female frogs which were in the small size class in the winter reached the large size class by the next summer.

2.2.5 Individual Growth

For California red-legged frogs that were recaptured at least once, the changes in length and mass were examined over time. Growth rates for males and females were compared between different times of year. Frogs caught in winter were compared to frogs caught during the rest of the year to evaluate

whether similar-sized frogs weighed less during winter, when food may be less abundant.

2.3 Reproduction

2.3.1 Calling

Aural surveys for calling males were conducted to determine the distribution of calling males within and between ponds, and the time of the year in which calling occurs. Aural surveys were conducted from outside of or at the opposite sides the ponds, since wading at close distance often caused the frogs to cease calling. Usually these surveys were conducted simultaneously to visual and capture surveys, and the numbers of frogs recorded indicate the how many different individuals were heard over a period of at least one hour.

2.3.2 Egg Masses

Egg masses were searched for by surveying the ponds as thoroughly as possible by wading and using float tubes. Approximately the first 2 meters of the emergent vegetation from the perimeter was searched. In late-February and early-March 1997, Ponds 2, 4 and 5 were completely searched once. In 1998, Ponds 1, 2, 4, and 5 were searched completely three times from late-January through March. For each egg mass the pond section number, water depth, substrate to which it was attached, distance from shore, surrounding vegetation type and estimated density, and developmental stage were recorded.

2.3.3 Metamorphosis

The pumps malfunctioned in August 1997 and July-August 1998, causing the water levels in the ponds to quickly drop. I was interested in whether there were still California red-legged frog tadpoles which had not yet metamorphosed and would be at risk of desiccation. In 1997 I set 10 unbaited steel minnow traps in each of Ponds 4 and 5 at 1400 hours and checked them at 2200 hours. In 1998 I set minnow traps in Ponds 2, 4 and 5 when the water levels had dropped substantially. The sampling effort was unequal between the ponds in 1998, and the number of tadpoles and metamorphs trapped is related to the trapping effort per pond (number of traps/days sampled). Late-stage tadpoles and recently-transformed frogs (metamorphs) tend to aggregate in the same areas of the pond for at least the first few weeks following metamorphosis (personal observation). Both tend to bask in warm shallow water, especially among aquatic vegetation, and flee from danger by diving under water. California red-legged frog metamorphs and late-stage tadpoles are readily caught in unbaited minnow traps (see Christopher 1996b). Therefore, the assumption can be made that capture probabilities using minnow traps are similar for late-stage tadpoles and metamorphs. A comparison of the ratio of metamorphs to tadpoles trapped within a short time period can indicate that there were differences in developmental rates between the ponds. Ponds in which larval development was faster may produce frogs with higher fitness.

Visual and capture surveys were conducted for metamorphs during the late-summer and fall annually from 1996 through 2000. Ponds 4 and 5 were surveyed at night using the methods described in Sections 2.2.1 and 2.2.2. Metamorphs that were seen on the trails were also counted. Metamorphs were given a toe clip which indicated the area in which they were originally caught (Section 2.2.1.2) to determine whether recaptured metamorphs moved between sites.

Daytime surveys were conducted to evaluate microhabitat and temperature selection by metamorphs. These surveys were conducted on three days in late-September/early-October 1999, between 1500 and 1630 hours. The margins of Pond 4 which had moderately dense vegetation were carefully searched, and the inside of the pond was surveyed using a float tube. There were no "margins" at Pond 5 since the dense emergent vegetation extended onto the shore, and the open water on the inside of the pond was surveyed by wading as described for night surveys. Water temperature was measured at the immediate location in which each metamorph was observed. Water temperature was also measured at several microhabitats in each pond - the shallow pond margins, and 5 centimeters below the water surface in pondweed (*Potamogeton* sp.), open water, and among dense emergent vegetation. In each of these microhabitats, water temperature was measured at four randomly chosen places per pond. Air temperature was also recorded. The ambient temperature measurements were performed immediately following the metamorph surveys, and were completed within one hour.

Metamorphs were not detected during the day at Pond 5, so only the temperatures measured at Pond 4 were used in the analysis. Data for the microhabitats were not normally distributed, and a non-parametric one-way analysis of variance was used to test the null hypothesis that the water temperature did not differ between microhabitats (Kruskal-Wallis test). The second analysis included the metamorph water temperature data, and used a Kruskal-Wallis one-way analysis of variance to test whether there was a difference in water temperature between the five areas. Pairwise mean comparisons were used to determine if the areas selected by metamorphs differed from the other microhabitats (Dunnett two-sided test).

2.4 Bullfrogs

Bullfrogs, a non-native species, were first observed at the Waterfowl Ponds during my initial survey in 1995. Thereafter, they apparently disappeared and did not recolonize until a few years later. Since bullfrogs have been implicated as a threat to native frog populations including the California red-legged frog (Moyle 1973, Fisher and Shaffer 1996, Kupferberg 1997, Kiesecker and Blaustein 1998), the bullfrog invasion was studied at the Waterfowl Ponds to determine if they may pose a threat to the California red-legged frog.

2.4.1 Relationship With Rainfall

The chronology of bullfrog sightings is reviewed. The timing of bullfrog invasions is discussed along with annual differences in the timing of rainfall.

2.4.2 Relationship With Water Temperature

Almost all of the bullfrogs at the Waterfowl Ponds have been seen or heard calling from Pond 4. I tested the hypothesis that Ponds 4 and 5 differ in water temperature. A difference in water temperature may influence site selection by bullfrogs since they are less cold-tolerant than most species of frogs (Moore 1942, Fitch 1956) and they may have better reproductive success at sites with increased water temperatures (Moore 1942, Hedeon 1975).

Water temperature was measured on a weekly basis during the peak of bullfrog activity, from 24 May to 29 July 2000, with the exception of one week that was skipped. Water temperature was measured at Ponds 4 and 5 in the open water at least 1 meter away from emergent vegetation, at depths of 10 centimeters and 1 meter below the surface. The exact locations for temperature sampling were randomly selected. If the measurements occurred within dense pondweed, a note was made. Measurements were

made between 1500 and 1730 hours. Four measurements were made per depth per pond on each sampling day, and the means of these four measurements were used in the analysis. Water temperature data from 1999 (Section 2.3.3) were included in the analysis. The data were normally distributed, and a paired-sample t test was used to test the null hypothesis that water temperature did not differ between Ponds 4 and 5. The pairs were the mean temperature taken on the same day and the same depth at the two ponds. The same analysis was repeated with a subset of the data, using only those measurements taken at the pond margins and at 10 centimeters deep. These microhabitats would represent the temperatures bullfrogs would be exposed to while active.

Temperature extremes experienced near the water surface were also evaluated for Ponds 4 and 5. At each pond a PVC pipe was stuck into the pond bottom and a mercurial maximum/minimum reading thermometer was attached at 10 centimeters below the water surface. The thermometers were placed in open water at least 1.5 meters away from emergent vegetation and pondweed. The maximum and minimum values were recorded on a weekly basis from 3 June through 23 July 2000, with the exception of one week that was skipped. Data for minimum temperatures were not normally-distributed, and non-parametric techniques were used. A Wilcoxon signed ranks test was used to compare minimum temperatures at Ponds 4 and 5 using pairs of measurements that were recorded over the same time periods. The same type of analysis was used for the maximum temperatures, however, since the data were normally-distributed, a paired t test was used.

Water temperature was measured at a bullfrog egg mass that was found in Pond 4. This was compared with the ambient water temperature at Pond 4 near the surface of the water measured at about the same time. The ambient water temperature measurements were made at 4 randomly-chosen locations 10 centimeters below the water surface. A Mann-Whitney U test was used to

test the null hypothesis that the water temperature was the same at the egg mass and the ambient surface water.

The influence of pondweed on near-surface water temperature was evaluated for Pond 4. The actual values were used to compare water temperature in mats of pondweed to that of open water. These measurements were taken 10 centimeters below the water surface at randomly-chosen areas. The data were normally distributed, and a one-way analysis of variance was used with the date of sampling as a covariate.

The temperatures measured at Ponds 4 and 5 were compared with two other ponds on VAFB which have high densities of bullfrogs (the lowermost Pine Canyon Lakes) and a site in which there are relatively low densities of bullfrogs (Mod III) (Christopher 1996b). Water temperature was measured at depths of 10 centimeters and 1.0 meter below the water surface, with 4 measurements made at each depth in different areas of the pond. Measurements were made at least 1 meter away from emergent vegetation. Water temperature was measured from the floating fishing piers at the Pine Canyon Lakes, and at randomly-selected sites at Mod III. The lowermost Pine Canyon Lake was sampled on two days, and the other sites were sampled only once. Measurements at these sites were made on the same days that the Waterfowl Ponds were sampled.

2.5 Species List

All species of reptiles and amphibians that were observed during work at the Waterfowl Ponds were noted, and a species list was prepared. Nomenclature follows Collins (1997).

3.0 RESULTS AND DISCUSSION

3.1 Habitat

3.1.1 Distribution of Captures

Habitat maps for Ponds 1, 4 and 5 are given in Figures 8, 9, and 10, respectively. The ponds were divided into sections to aid in the visual interpretation of California red-legged frog microdistribution and habitat use. Captures were divided into breeding season (December 1 through April 30) and non-breeding season (May 1 through November 30). Ponds 1 and 2 were surveyed only a few times during the breeding season, whereas Ponds 4 and 5 were surveyed extensively between October 1996 and September 1998. Frogs were also captured in 1999, but section numbers were not recorded.

In Pond 1, a total of 18 captures were made in Sections 1 through 6, which were the only sections that were surveyed. There was no apparent concentrations of frogs in any area. Two frogs were captured in Pond 2.

In Pond 4 during breeding season, 2 captures were made in Sections 2B and 3B, 5 captures were made in Sections 8 through 10 (with all but one on the B side of the pond), and 12 captures were made in Sections 11 and 12. There appeared to be a concentration of frogs on the B side and lowermost sections (11 & 12) of Pond 4. Most frogs were caught at areas with only moderately-dense vegetation or open water to the shore (see Figure 9). The A side of the pond lacked this type of microhabitat, especially as the extent of emergent vegetation increased (Figure 9 right). During non-breeding season, captures in Pond 4 were nearly-evenly distributed throughout the pond. Eight captures were made in Sections 1- 3, 6 captures in Sections 4-6, 5 captures in Sections 7-9, and 9 in Sections 10-12. There were slightly more captures made on the B side of the pond in comparison to the A side.

The upper middle portion of Pond 5 (Sections 1B through 5 B) which was too deep to wade was not surveyed during breeding season. Survey effort was spread almost evenly throughout the other areas of the pond which could be waded. During breeding season, 9 captures were made in Sections 5 - 7 C, 8 captures in Sections 8 - 10 C, and 9 captures in Section 11 C. Only 5 of these were made in the A and B regions, and these were in Sections 11 and 12. The areas on the C side of the pond where 81% of the frogs were obtained were small pockets of open water and sparse vegetation near the shore (Figure 10). The "hot spot" for captures at 11 C was the largest open water patch (Figure 10). Two captures were made outside of the pond. One frog was captured on the trail between Pond 5 and the willows to the southwest of the pond, and one frog was captured in the willows. During non-breeding season in Pond 5, the total survey effort was evenly distributed throughout the pond. Four captures were made in Sections 1 - 3, 15 were made in Sections 4 - 6, 5 captures in Sections 7 - 9, and 41 captures were made in Sections 10 - 12. There was no selection for the C side of the pond during non-breeding season: 22 (33%) of the captures were made in the C region. The highest number captures were made in areas of the pond that had the most open water which was connected to the shore (Figure 10). However, capture probability is greater in areas with extensive open water. For an unbiased evaluation of microdistribution, a technique such as radio tracking should be used.

Recaptures of marked frogs revealed some movement between sites. Two frogs went from Pond 1 to 4, one went from Pond 1 to 5, two went from Pond 4 to 5, and one went from Pond 5 to 4. Two marked frogs were found trapped in a water control gate between Ponds 1 & 4: one of these was first caught in Pond 4 and the other from Pond 5.

3.1.2 Changes in Habitat

The coverage by emergent vegetation increased throughout the period of the study. Figures 9 and 10 show a short-term increase in the extent of emergent vegetation. By 2000, no open water was visible from the perimeter of the ponds, and the extent of open water in the center had also decreased. Ponds 1 and 5 probably had about 90% cover by cattails. In the fall of 1999, a controlled-burn was conducted at Pond 1 in an attempt to reduce the cover by cattails. This effort resulted in increasing the amount of open water throughout the winter, but by May 2000 the cattails had completely grown back.

The open water in the center of Pond 4 becomes filled with a densely-growing submergent plant, pondweed, every summer. In 2000 it started to send shoots up to the surface from the bottom by mid-June. By early-July, the plant had formed thick mats at the surface of the water which provide a substrate for the attachment of green filamentous algae. The presence of these mats of vegetation increases the surface water temperature (see below). California red-legged frogs and metamorphs, bullfrogs, southwestern pond turtles (*Clemmys marmorata pallida*), and flying insects were frequently observed sitting on top of these mats. In the fall, the plant dies and the stems form a spaghetti-like decaying mass which floats just below the surface. By winter the water is usually open to the bottom. This plant is not present in Pond 5.

3.2 Population Trends

3.2.1 Mark-recapture

A total of 199 captures were made, and 144 of these were unique (first-capture). 9 recaptures had been made in part because they had radio transmitters, or were caught using some method other than regular survey, and these were omitted from the calculation of recapture rates. Of the

remaining recaptures, 23 frogs were captured twice, 7 were captured 3 times, and 3 were captured 4 times. One frog was clipped as a metamorph and recaptured when it was 77 mm. Table 1 shows the recapture rates across arbitrarily-chosen survey intervals. The decrease in the proportion of marked frogs in the last two time intervals suggests an increase in the proportion of new frogs in the population.

Chao's (1987) method gives a population estimate as well as a 95% confidence interval for population size. The estimated population size increased over time, and there could have been as many as 643 California red-legged frogs present (Table 2). The confidence interval is large for 1998-1999 due to decreased number of captures as a result of reduced survey effort (see Table 1). By 1999, there were several hundred adult California red-legged frogs at the Waterfowl Ponds.

3.2.2 Visual Survey

The maximum number of adult (>55 mm SUL) California red-legged frogs within a survey period tended to increase over the years of the study (Table 3). In Pond 4, only a few frogs were seen in 1998 in part because only about 9% of the pond was surveyed that year. In addition, since there were only two surveys were performed, and the number of frogs seen during visual surveys is quite variable, there is low confidence in the estimate of how many frogs occupied the pond at that time. While the data reflect a slight decrease in Pond 5 for the year 2000, this is related to the fact that a smaller area was surveyed that year in comparison to previous years due to the encroachment of dense emergent vegetation. Therefore, the overall trend appears to be an increase in the population size over time for both ponds.

In Pond 5, the open water areas in Sections 10B and 11B, and the short passageways into the A and C regions of Sections 10 and 11 (Figure 10 right)

were the only areas surveyed in 1999 and 2000. The 1999/2000 survey area is 4.5% of the total area of the pond. Using the maximum count of frogs seen in Pond 5 in 2000, and assuming that the density of frogs was evenly-distributed throughout the pond, there could have been as many as 578 frogs in the pond at that time. In Pond 4, 43% of the surface area of the pond was surveyed in 1999 and 2000. Assuming equal densities throughout the pond, there could have been as many as 219 frogs in Pond 4 in 2000. Pond 2 was dry in Fall 2000, but Pond 1 had water. A conservative estimate of 75 frogs in Pond 1 gives an estimated total of 872 adult California red-legged frogs at the Waterfowl Ponds in 2000. While it may not be valid to assume equal densities throughout the pond due to microhabitat preferences, this may be balanced in a conservative direction by the use of visual survey data. The number of frogs detected by visual survey is thought to underestimate the number of frogs present because an undetermined proportion may be under water on any given night (Jennings and Hayes 1988, 1990). Nevertheless, there appears to be enough data to suggest that the population of California red-legged frogs at the Waterfowl Ponds can be considered quite large relative to other estimated population sizes. Jennings et al. (1992) classified a breeding population as "large" if it contained >350 adults, and stated that populations of this size were known from only three areas (none of which were at VAFB).

3.2.3 Demography

Captured California red-legged frogs were divided into size classes and by sex to visualize the demography of the population over time (Figure 11). Young produced in 1996 (metamorphs) comprised 33% of the frogs that were captured. Frogs in the small size class either could have been produced at the ponds in 1995 (when only Pond 5 retained water in the summer) or they had emigrated to the site. When sample sizes were large in 1997 and 1998, the sex ratio of large frogs was nearly 1:1 (Figure 11). The large proportion of metamorphs in 1997 and 1998 is related to the fact that most of the

metamorphs were caught when the pumps were off, and the water levels in the ponds had dropped dramatically. When the water level dropped below the band of emergent vegetation in Pond 4, adult frogs with radio tags moved to Pond 5, which had deeper water at that time (Christopher, unpublished data). Many metamorphs (and tadpoles) were crowded in the shallow water remaining in the bottom of Pond 4, or were found on land, making them relatively easy to catch. While the same number of metamorphs were caught in 1997 and 1998, they comprise a smaller proportion of the catch in 1997 because more surveys were conducted at times when the water levels were normal. Nevertheless, there were good numbers of metamorphs produced in 1997 and 1998, and their apparent survival is indicated by an increase in the proportion of small frogs in 1999 (Figure 11). These data indicate that California red-legged frogs reproduced successfully at the Waterfowl Ponds throughout the study, and it appears that there has been some survivorship to adulthood each year. In addition, there appears to have been no deficiency in any size class of frogs over the period of the study.

3.2.4 Individual Growth

Female (Figure 12) and male (Figure 13) California red-legged frogs grew rapidly during spring and summer months, and several individuals went from the small size class (57 - 90 mm SUL) to the large size class (>90 mm SUL) within 6 months. Large frogs are probably sexually mature, and the rate of growth for these individuals was lower than for small frogs. This pattern corresponds with studies on other species of anurans in which most individual growth has been documented within a one or two years after transformation, and thereafter growth is minimal (Turner 1960). As expected, growth rates appeared to be greater during spring and summer months in comparison to fall and winter months (Figures 12 & 13). In many species of anurans, postmetamorphic growth rates are correlated with temperature and

length of the growing season (Turner 1960), and in some species most growth occurs rapidly over a short period of time (Martof 1956, Turner 1957).

The slight decrease in the length of some individuals is due to error in measurement (see Section 2.2.5). In addition, short-term variability in mass of anurans can be attributed to gut contents. Actual weight loss may occur during periods of low food availability. To determine if there was any pattern of weight loss during winter months, I plotted the mass of frogs as a function of their length when caught in winter (14 December - 2 March) versus non-winter (Figure 14). For both males and females, similar sized frogs did not appear to weigh less in winter. Perhaps the observed decrease in activity exhibited by this species during the winter compensates for any potential decrease in food availability.

For many anuran species, females attain larger sizes than males (Turner 1960), and California red-legged frogs are known to fit this pattern (Hayes and Miyamoto 1984). Females (sample mean = 103.8 mm SUL, range = 71-129 mm SUL, $n = 37$) were significantly larger than males (sample mean = 94.2 mm SUL, range 65-111 mm SUL, $n = 43$) in the subset of frogs captured in August and September of 1997, 1998, and 1999 (Independent samples t test: $t = 3.0666$, $P = 0.003$).

3.3 Reproduction

3.3.1 Calling

Breeding choruses took place between November and April (Figure 15). November 1997, December 1997, and January 1998 had relatively low survey effort and thus the number of frogs calling during those periods is probably under-represented. Nevertheless, it can be inferred that calling reaches a peak January through March.

Pond 1 had the greatest total number of California red-legged frogs heard calling at any one pond (Figure 16). Since the effort for calling surveys at Pond 1 was almost half that of Ponds 4 and 5, Pond 1 seems to be an important breeding site. Calling frogs were located mainly in Sections 1 through 4 of Pond 1 (see Figure 8). Calling sites were usually small openings within a dense patch of cattails, in which there were bent over cattails that the males perched upon while vocalizing (Figure 17). Popular areas for calling in Pond 4 were the northwestern edges of the pond, especially the B side and Sections 1 through 8 (see Figure 9). These were areas in which there was relatively low vegetative cover near the shore. None were recorded as calling from Sections 10 through 12 in Pond 4. In Pond 5, most calling frogs were heard from Sections 1 through 6, and slightly more were heard on the A side of the pond (see figure 10). In contrast to the other ponds, the areas used in Pond 5 had dense cattails.

3.3.2 Egg Masses

The egg mass surveys in 1998, in which each pond was searched completely three times, revealed that most of the egg masses were laid in Ponds 1 and 2 (Figure 18). Because Pond 2 had the lowest density of vegetation, the probability of finding egg masses was greater than at the other sites. The vegetation density at Ponds 1, 4 and 5 in 1998 was such that search efficiency was about the same. Therefore, coupled with the results of the calling surveys, Pond 1 seems to be the most important site for breeding. Unfortunately, Pond 1 was not searched for egg masses in 1997. Oviposition sites in Pond 1 were generally of moderate vegetation density and water depth (Figure 19).

In Pond 4, egg masses were laid in water 25 - 40 centimeters deep, and were located 2 - 4 meters from shore. Most egg masses were found in Sections 2B and 8B, where there was some open water to the shore (Figures 9 and 20).

These areas also had high numbers of calling males. In 1997 one of the egg masses was partially out of the water - it had been attached to a bulrush stem which had either grown quickly or the water level had dropped, and 15 centimeters in length of the egg mass was exposed to air. This situation highlights the need for stringent water level management during California red-legged frog breeding season. The other substrates used did not result in stranding out of the water, including cattails, sedge, shrubs, dead annual plants, willows, dead bulrushes that were bent over, dead grass, submergent macrophytes, or on the bottom of the pond. Only 2 egg masses out of the total of 9 from both years at Pond 4 were found attached to live bulrushes.

The failure to detect egg masses in Pond 5 in 1998 is surprising considering that 10 were found in 1997. In late-summer 1998, California red-legged frog tadpoles were trapped at Pond 5 (see Section 3.3.3). Therefore, breeding did take place in Pond 5 that year, but the egg masses must have either been laid within dense cattails where we could not survey or oviposition took place prior to or following the egg mass surveys. Areas which had been used as oviposition sites in 1997 (Sections 1 through 6; see Figure 10) had moderately dense cattails in shallow (30-40 cm deep) water at the perimeter of the pond. By 1998, this microhabitat was no longer present as dense cattails filled in these areas.

The water depth at the 1998 oviposition sites differed between ponds (Kruskal-Wallis test: $H = 14.12$, $df = 20$, $P = 0.0009$). The egg masses in Pond 2 were laid in significantly deeper water (mean 70 cm, range 45-95 cm) than at Pond 1 (mean 40 cm, range 30-65 cm) and Pond 4 (mean 28 cm, range 20-35 cm) (Bonferroni Pairwise comparisons, $P = 0.0017$ and $P = 0.0001$, respectively). Pond 2 dries down more quickly than the other ponds, but it would be incredible to think that the frogs could somehow anticipate this. Unfortunately, water temperature was not measured in 1998, but it is possible that water temperature influenced oviposition site selection.

3.3.3 Metamorphosis

In 1997, 1 California red-legged frog tadpole was trapped from Pond 4 and 3 from Pond 5. This short period of trapping indicated that there were untransformed tadpoles present during the period in which the water levels dropped substantially due to pump failure. Pond 4 dried down to a shallow pool, which probably increased predation on tadpoles (raccoon tracks were seen encircling the pool and herons were observed feeding at the water's edge) and increased competition due to crowding. In addition, this event could have resulted in tadpoles to metamorphosing at a smaller size, which can lead to decreased individual fitness (Collins 1975, Wilbur et al. 1978).

In 1998 there were 2.3 times more tadpoles and metamorphs trapped in Pond 2 in comparison to Pond 5, and 3.4 times more in Pond 2 than Pond 4, when total number of tadpoles and metamorphs trapped is given as a function of trapping effort. In addition, more metamorphs than tadpoles were trapped in Pond 2, whereas Ponds 4 and 5 had a higher proportion of tadpoles (Figure 21). This suggests that frogs metamorphosing from Pond 2 may have had greater developmental rates, which can result in higher individual fitness, relative to those from Ponds 4 and 5. Within a cohort, larvae which metamorphose sooner may be larger at the end of the first season due to increased length of time to feed terrestrially before winter (see Semlitsch et al. 1988). Larger juvenile body size may lead to earlier age at first reproduction, larger clutch sizes (Collins 1975), and higher probability of mating for males (Wilbur et al. 1978). In addition, tadpoles which experience higher larval growth rates may be better competitors (Travis 1980) and have higher survivorship due to decreased predation in the aquatic environment (Wilbur et al. 1983).

The numbers of metamorphs seen during late-summer and fall night surveys are given in Table 4. From 1997 onward, metamorphs were produced in both

ponds on an annual basis. Data were quite variable both within and between years at a given pond. A comparison of the numbers seen between the two ponds may not be valid because survey efficiency and size of the survey areas differed significantly. These data probably greatly underestimate the number of metamorphs present since no marked metamorphs were recaptured within the same year. Metamorphs were frequently found out of water on the trails. After around 1 December each year metamorphs were no longer detected during the night surveys, and they remained absent throughout the winter. Further study is needed to investigate whether metamorphs make short movements between ponds, move overland to other areas such as the Santa Ynez River, or if they exploit terrestrial habitats for a portion of their life.

During the day, metamorphs were found only in the shallow margins of Pond 4. Water temperature did not differ between the microhabitats (margins, open water, pondweed, emergent vegetation; $H = 2.41$, $df = 3$, $P = 0.4920$). However, when the temperature data from the locations of the metamorphs were added into the analysis, the groups were significantly different ($H = 25.83$, $df = 4$, $P = 0.0000$). The water temperature at the metamorphs was significantly greater than that measured within the emergent vegetation ($P = 0.0002$), the open water ($P = 0.0011$), and areas at the margins that did not have metamorphs ($P = 0.0002$), but were not significantly different than temperature measured in the pondweed ($P = 0.3511$; error MS = 2.73, error $df = 73$). A difference of only a few degrees Celcius was relevant in temperature selection by metamorphs (at metamorphs: mean = 20.6, range = 17.5 - 26.0, $n = 35$; margins without metamorphs: mean = 18.4, range = 15.5 - 21.0, $n = 15$).

3.4 Bullfrogs

Bullfrogs invaded the Waterfowl Ponds on at least two separate occasions since the Waterfowl Ponds were rehabilitated (Table 5). They were apparently eliminated once due to drying of the ponds in fall 1995. From winter 1996 through summer 1997, bullfrogs apparently remained absent, while the California red-legged frog population became established (Table 5). One juvenile bullfrog was found in November 1997, and by summer 1998 several adult bullfrogs were present (Table 5). Bullfrog densities remained low through fall 2000, and the maximum number seen on any one night survey was 8 (Table 5). Numbers of bullfrogs seen during surveys did not appear to increase between 1998 and 2000.

Marked bullfrogs have been recaptured at locations as much as 1600 meters (5250 feet) away from the original point of capture over a period of one year (Ingram and Raney 1943). In less than 3 weeks, one bullfrog was found to have moved 1219 meters (4000 feet) (Ingram and Raney 1943). Ingram and Raney (1943) proposed that most bullfrogs which undertook long overland movements mainly followed stream courses to move between ponds. The dense riparian woodland south and southwest of the Waterfowl Ponds may be suitable habitat for overland movements of bullfrogs. Bullfrogs are present in high densities in the Santa Ynez River, and they occur at several ponds in the floodplain on VAFB (Christopher 1996b).

Almost all of the bullfrog sightings and those heard calling at the Waterfowl Ponds were from Pond 4. The exceptions were one bullfrog heard calling from Pond 2 on one occasion in July 1998, one juvenile found in Pond 5 in November 1997, and one seen in Pond 5 in August 2000 (Table 5).

Bullfrogs were heard calling at the Waterfowl Ponds only in July and August of each year (Table 5). One bullfrog egg mass was found on 17 June 2000, even

though they were not calling at that time from the Waterfowl Ponds. The egg mass was not removed for the purpose of future research on the invasion dynamics of the bullfrog in a coastal habitat. Bullfrog larvae were not caught in minnow traps which were set late in the summers of 1997, 1998, and 1999. Juveniles apparently have not been produced at the Waterfowl Ponds to date as no recently-transformed bullfrogs have been observed.

3.4.1 Relationship With Rainfall

There appears to be some correspondence between the timing of the bullfrog invasions with the seasonal timing of rainfall. Gibbons and Bennett (1974) found that terrestrial activity of the bullfrog is correlated with precipitation. Wet conditions would prevent desiccation while in terrestrial habitats. During storms predators may be less likely to detect these vulnerable prey, and movement en mass may decrease the risk of predation through a saturation effect.

Bullfrogs are less cold-tolerant than most frogs (Moore 1942, Fitch 1956), and throughout North America they are the last frog to emerge in the spring (Viosca 1931, Smith 1934). While bullfrogs inhabiting the southeastern United States may be active year-round (Bury and Whelan 1984), throughout the rest of the country they are inactive or hibernate during the winter (Smith 1934). Bullfrogs usually emerge after air temperatures have reached 20-24°C and water temperatures are above 14°C (Willis et al. 1956, Treanor and Nichola 1972). Therefore, early-season rainstorms coupled with cool temperatures may be inappropriate for overland movement of bullfrogs in California. Overland movements of bullfrogs have been reported to be most frequent during rainy nights when temperatures are relatively warm (Raney 1940, Gibbons and Bennett 1974).

A comparison of rainfall records (Figure 22) with the invasion history of bullfrogs at the Waterfowl Ponds (Table 5) suggests that invasions may have taken place when rainfall occurred relatively late in the season (March - May). Late-season rainfall occurred in 1994 and 1995 (Figure 22). Bullfrogs could have emigrated to the Waterfowl Ponds at that time, or had already been established from emigration during previous years. Bullfrogs were first detected at the Ponds in May 1995. When the ponds dried in fall 1995, the bullfrogs probably either moved to another area or died. In 1996 and 1997, during the period when bullfrogs remained absent, little to no rainfall occurred late in the season (Figure 22). Immediately following the first rain storms in November of 1997, one juvenile bullfrog was found. Since there was a high intensity of survey effort in summer of 1997, this bullfrog was probably a recent arrival. There was a considerable amount of late-season rainfall in 1998, which was followed by the establishment of bullfrogs by summer 1998. In 1999 and 2000, there was some precipitation in March and April, but not in May (Figure 22). It is not known if there was any emigration or immigration of bullfrogs during this time since their numbers seemed to have stayed about the same.

3.4.2 Relationship With Water Temperature

Most bullfrogs at the Waterfowl Ponds were detected at Pond 4. Investigation concerning the apparent selection of this pond is of interest for understanding the ecology of bullfrog invasions. The most obvious differences between the ponds are that Pond 4 has the deepest water, the least amount of cover by emergent vegetation (Figures 8 - 10), and the presence of pondweed. Bullfrogs appear to prefer warmer temperatures as evidenced by their activity periods (Viosca 1931, Smith 1934), microhabitat selection by adults within a pond (McAlpine and Dilworth 1989), and by tadpoles under experimental conditions (Crawshaw et al. 1992). Water temperature may be influenced by the vegetation characteristics of the ponds. Shading by emergent vegetation

may decrease water temperatures, and pondweed may increase surface water temperatures by decreasing the mixing of cool water at the bottom of the pond with that warmed by the sun at the surface.

In every analysis, Pond 4 had higher water temperatures than Pond 5. Paired comparisons of temperatures sampled at all habitats and all depths indicated that Pond 4 was warmer than Pond 5 ($t_{0.05(2), 19} = 8.55, P = 0.0000$). Analysis of a subset of those data using only temperatures measured at the water surface and at the pond margins, which are microhabitats used by bullfrogs while active, also showed that Pond 4 was warmer ($t_{0.05(2), 10} = 6.34, P = 0.0001$). Minimum temperatures recorded at Pond 4 were greater than at Pond 5 ($Z = -2.06, t_{0.05(2), \infty} = 1.96, P = 0.0394$) and maximum temperatures recorded at Pond 4 were higher than at Pond 5 ($t_{0.05(2), 5} = 5.22, P = 0.0034$).

The bullfrog egg mass found in Pond 4 was laid on top of a dense mat of pondweed. Water temperature measured at the egg mass was greater (mean = 25.1°C , $n = 4$) than the ambient temperature of the near-surface water (mean = 20.4 , $n = 4$; $U_{0.05(2)4,4} = 0.00, P = 0.0172$). Using the data collected throughout the summer at Pond 4, surface water was warmer in pondweed in comparison to open water lacking pondweed ($F_{0.05(1), 1, 57} = 7.31, P = 0.0090$). The presence of pondweed may increase the suitability of the pond for bullfrogs by increasing the water temperatures at the surface of the pond where bullfrogs are active and where oviposition occurs.

At sites on VAFB, there appears to be a positive correlation between bullfrog density and water temperature (Table 6). The water temperatures measured at Pond 4 were similar to those measured at Mod III. Mod III also has relatively low densities of bullfrogs (Christopher 1996b). The Pine Canyon Lakes, which had the warmest temperatures, have relatively high densities of

bullfrogs (Christopher 1996b). Pond 5, which is almost totally avoided by bullfrogs, had the lowest water temperatures.

The length of the larval period of the bullfrog is shorter in warmer regions of North America (Bury and Whelan 1984). Tadpoles can metamorphose within one season in the southeastern U.S. (Viosca 1931) and California (Cohen and Howard 1958), but may overwinter as many as three times in northern latitudes (Wright and Wright 1949, Leviton 1971). Even though the differences in water temperature between the sites given in Table 6 are only a few degrees Celcius, the success of the bullfrog at any given site may be affected by the number of days above some critical temperature which would allow tadpoles to metamorphose within one season. At sites in which metamorphosis can be accomplished within one season, the success of bullfrog invasions may be greater due to shorter time to first reproduction, decreased larval competition (Licht 1967), and decreased predation on larvae (Cecil and Just 1979).

3.5 Species List

The amphibian and reptile species observed at the Waterfowl Ponds are given in Table 7. Of note is the occurrence of the southwestern pond turtle (*Clemmys marmorata pallida*), which is a California Department of Fish and Game Fully Protected and a Special Concern species (California Department of Fish and Game 2000). A southwestern pond turtle possessing shelled eggs was found on the trails at the Waterfowl Ponds. Juvenile turtles less than two years old have been observed on the edges of the ponds. Adult pond turtles were frequently observed basking in or on top of pondweed in Pond 4. Another type of basking site which was used was mats of cattails leaning over into the water (Figure 23).

4.0 RECOMMENDATIONS FOR MANAGEMENT

4.1 Openings In the Vegetation

The desire to create open patches within the perimeter band of vegetation to permit the view of open water does not conflict with the microhabitat requirements of the California red-legged frog. This study demonstrated that areas with low to moderate vegetative density near the shore were used during the breeding season. Apparently this was due to the suitability of these sites for breeding, as this microhabitat was often used by calling males and for oviposition. Metamorphs were also found to use these areas during the day.

The following guidelines should be followed to potentially enhance the habitat for the California red-legged frog, as well as to prevent direct impacts to individuals, if openings in the vegetation are to be created.

1. **Site Selection.** Openings in the vegetation should be constructed in areas which previously had low vegetation density, and were used as breeding sites by the California red-legged frog. In Pond 1, one opening could be made within Sections 1 through 3 (Figure 8). In Pond 4, one or two openings could be made in Sections 2B and 8B (Figure 9). In Pond 5, one opening could be made in the area of Sections 2A, 3A and 4A (Figure 10). The openings should be constructed where the band of vegetation is presently at its minimum width.
2. **Timing.** Vegetation removal should be done in late-September through November. If substantial precipitation occurs during this period, the project should be postponed until the following year. No more than one pond should be done per year.
3. **Preparation.** Prior to any human activity in the aquatic habitat, the water level of the pond should be lowered to expose the entire work area. The

frogs are likely to move with the water level, or they may move to adjacent ponds. Water could be pumped to Ponds 1 and 2 to facilitate water levels for breeding season. The intake hose for the pump should be placed at the edge of the water in a bucket which has screened openings, and closely monitored.

4. Vegetation Removal. The area of vegetation removal should cover no more than about 5 meters (16.5 feet) in length along the pond's perimeter. Immediately prior to the removal of vegetation, the work area should be surveyed to confirm the absence of sensitive species. Manual removal of vegetation using hand tools is the preferred method. Only if this method proves to be ineffective should herbicides be used. A thorough literature search on the potential effects of different commercially-available herbicides on ranid frogs, and consultation with the U. S. Fish and Wildlife Service, should be undertaken prior to the use of herbicides. To prevent the regrowth of vegetation, a synthetic weed barrier should be stapled to the pond bottom.
5. Maintenance. If enough organic material collects on top of the weed barrier to permit dense emergent vegetation to grow, the water level may be dropped periodically so that it can be removed. Again, this should be performed in late-September or November, and only one pond should be done at a time. This strategy may double as bullfrog control (see Section 4.8). Low-growing and sparse vegetation should not be removed from these areas, as this microhabitat is used for the attachment of egg masses by the California red-legged frog.
6. Use. Foot traffic to the edge of the water near the cleared areas should be discouraged by allowing low-growing terrestrial vegetation to grow between the present perimeter trails and the pond edge. If necessary, signs could be placed which emphasize the environmental sensitivity of these areas.

4.2 Floating Piers

The construction of floating piers through the perimeter band of emergent vegetation would probably have no negative impacts on the habitat of the California red-legged frog. In fact, the frogs may frequent the areas along the edge of the piers at night. Examples of these types of structures at VAFB can be seen at Pine Canyon Lakes. Since the adult frogs are nocturnal, and the metamorphs probably wouldn't be found in this type of situation, human use of the piers would not be likely to affect the behavioral patterns of the frog.

1. **Site Selection.** Floating piers would be feasible only in Pond 4, since it is the only site that has extensive open water. The best area for a pier would be Sections 10 and 11 (Figure 9), especially if openings in the vegetation as described above are constructed at the other end of the pond. The exact placement of the pier should be where the band of vegetation is of minimum width.
2. **Timing.** The project should be conducted in late-September through early-December. This is the period when the California red-legged frog is the least active.
3. **Preparation.** If the installation of the pier requires the total removal of emergent vegetation in the immediate area, the water level of the pond should be lowered to expose the entire work area. Water could be pumped to Ponds 1 and 2 to facilitate water levels for breeding season. The intake hose for the pump should be placed at the edge of the water in a bucket which has screened openings, and closely monitored. Alternatively, if the vegetation can be trimmed only to the water surface using hand tools, the water level would not need to be manipulated.
4. **Design.** Given a floating pier and a patch of open water, some visitors are bound to feel that the area could only be improved by the opportunity for fishing. I have talked to people who admitted to introducing fish to ponds at VAFB that they thought were suitable. Warm-water fish species such as

bass, sunfish, bullhead, catfish, and mosquitofish are voracious predators of California red-legged frog larvae. This situation may be avoided if all areas of the pier which are surrounded by open water are made into a blind, with sides high enough to discourage fishing.

5. Maintenance. Emergent vegetation which grows up around the pier should be periodically trimmed using hand tools.
6. Use. If evidence of foot traffic around the water's edge is found as a result of the newly-created access, signs explaining the environmental sensitivity of the area could be installed. If this is not successful, then fencing could be used. However, the nettles and other unfriendly plants which grow around the ponds should be sufficient to discourage people from wandering.

4.3 Rehabilitate the Other Basins

Instead of trying to manage the vegetation in Ponds 1, 4, and 5 to create a desirable situation for wildlife viewing, effort could be directed toward the rehabilitation of the basins 3 and 6 for this purpose (Figure 2). Since the California red-legged frog will probably colonize the new ponds soon after the pumps are turned on, it will be important to make all physical improvements and install all structures before the ponds are filled. A few guidelines follow.

1. Water Source. To create aquatic habitats at basins 3 and 6, new well(s), pump(s), and water lines would need to be installed. Water should not be diverted from the existing ponds.
2. Pond Design. To discourage extensive coverage by emergent vegetation, the basins should be excavated to a greater depth. Water depth could be measured at older ponds at VAFB to determine that which is necessary to inhibit growth of emergent vegetation. The minimum value is probably around 1.5 meters (5 feet). At areas around the pond perimeter where a

view of the open water is desired, the basins should be given very steep sides.

3. Creating Habitat For the California Red-legged Frog. If California red-legged frog habitat is to be intentionally created, there should be at least one area of the pond designated for coverage by cattails. Figures 23, 24 and 25 depict some of the benefits of cattails as a component of California red-legged frog habitat. A broad shallow shelf could be created for California red-legged frog breeding habitat. The water could be allowed to dry down a little in the summer and fall, exposing the shelf area, which would inhibit the growth of dense emergent vegetation.

4.4 Restrict Excessive Development

As a designated wildlife and natural resources area, management plans probably already preclude the over-development of the Waterfowl Ponds. With regard to the California red-legged frog, any future developments should discourage human disturbance near the shoreline of the ponds through the maintenance of the perimeter trails which are already in place. Trash receptacles which may attract raccoons, a predator of the California red-legged frog, should be placed only near Terra Road. Vehicle access to the site should continue to be prohibited to discourage the introduction of fish into the ponds by visitors. Large-scale removal of emergent vegetation, or any other activities which may raise water temperatures, should not be permitted as this may facilitate occupation by the bullfrog.

4.5 Decrease Water Fluctuations at Critical Periods

Close monitoring of the water levels and regulation of the fill rates should be conducted during the California red-legged frog's breeding period (December - March). This would help to prevent egg masses which are attached to vertical braces from becoming stranded out of water. In addition, the water level

should not be allowed to drop to more than 50% during the period that tadpoles are present (March through mid-September). The drop in water levels during the summers of 1997 and 1998 due to pump failure may have resulted in the mortality of some tadpoles due to increased predation and competition. In addition, a substantial decrease in water levels prior to the normal period for transformation may result in the production of smaller metamorphs, which have lower individual fitness.

4.6 No Mowing During Turtle Season

Southwestern pond turtles were observed on the perimeter trails in March and August. The turtles seen in March were probably returning to the ponds after their winter dormancy period which is spent in terrestrial habitats. Female turtles nest in upland areas in May and June (Rathbun et al. 1993). The turtles return to upland areas for the winter beginning the middle of August (Rathbun et al. 1993). Mowing should not be done during these periods when it would be likely to encounter turtles on the trails.

4.7 Cover Water Gates

The water control gates between the ponds act as pitfall traps. Two California red-legged frog were found trapped in the gates. Covers should be installed over the pits which would exclude frogs.

4.8 Future Monitoring

Population status of the California red-legged frog and the bullfrog should be monitored on a yearly basis as described in Section 2.2.2. If bullfrog metamorphs are found to be produced from the Waterfowl Ponds, or if the numbers of adults are found to increase substantially, effort should be made to control the population. While there is no method which has been proven

to be effective at controlling bullfrogs, the strategy most often suggested is drying up the habitat before the tadpoles can complete metamorphosis. Most or all California red-legged frog tadpoles should have reached metamorphosis by November, but bullfrog tadpoles would probably need to overwinter if eggs are usually laid in June. Therefore, November would be the appropriate time to dry a pond. Thus far, it appears that only Pond 4 is likely to need to be managed. If a pump is used to drain the pond, the intake should be screened to prevent take of any untransformed California red-legged frog tadpoles. In addition, a herpetologist should be present to relocate any animals which become stranded and to capture bullfrogs.

Future research on microhabitat use by the California red-legged frog should investigate where the metamorphs go during the winter following transformation.

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7.0 PERSONAL COMMUNICATIONS

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Table 1. Proportion of marked frogs caught by survey interval. Frogs that were caught because they were radio tagged or other non-random methods were excluded. Number of surveys is the total number of nights each pond was surveyed.

Survey interval	No. of surveys	No. of captures	Proportion marked
10/14/96-12/28/96	17	10	0.00
1/24/97-5/11/97	18	69	0.26
7/18/97-11/20/97	16	52	0.38
2/15/98-3/7/98	5	4	0.25
8/12/98-9/14/98	6	24	0.17
8/20/99-9/25/99	7	31	0.10

Table 2. Population estimate of California red-legged frogs at the Waterfowl Ponds derived from mark-recapture data (Chao 1987).

Time interval	No. unique individuals caught	Population size estimate	Population size range (95% C.I.)
1996 - 1997	93	201	126 - 276
1998 - 1999	52	328	13 - 643
1996 - 1999	144	402	255 - 549

Table 3. Number of California red-legged frogs observed during night surveys of the southernmost Waterfowl Ponds. In 1996, the surveys were conducted October 14 through December 28. For all other years, only surveys conducted between June 1 and September 30 are shown. Each number indicates the total number of frogs (> 55 mm snout-urostyle length) seen during that survey. In Pond 4, the survey area was about the same for each survey. In Pond 5, the survey area decreased over time due to the encroachment of dense emergent vegetation.

	1996	1997	1998	1999	2000
Pond 4	6, 3, 1, 5, 2, 2	8, 6, 4, 7	7, 18	22, 37, 51, 43, 21	45, 63, 67, 59, 94
Pond 5	7, 1, 0, 6, 0, 1, 3	12, 15, 14, 8	28, 10, 5	40, 35, 16	26, 20, 25, 19

Table 4. Number of California red-legged frog metamorphs observed during night surveys of the southernmost Waterfowl Ponds. In 1996, the surveys were conducted October 14 and 18. For all other years, only surveys conducted between July 18 and October 16 are shown. In 1997 and 1998, the water level in the ponds dropped significantly during the peak metamorphosis period, which greatly increased the probability of finding metamorphs. Each number indicates the total number of frogs (≤ 55 mm snout-urostyle length) seen during that survey. In Pond 4, the survey area was about the same for each survey. In Pond 5, the survey area decreased over time due to the encroachment of dense emergent vegetation.

	1996	1997	1998	1999	2000
Pond 4	0, 0	6, 2, 35, 7, 6, 0	6, 9, 0	1, 0, 2, 2	6, 4, 7, 13
Pond 5	6, 1	0, 0, 5, 9, 0, 3	39, 40, 6	0, 1, 4	2, 1, 1, 1
Trails	0, 0	1, 0, 1, 0, 1, 0, 0	1, 1, 0	4, 0, 0	0, 0, 0, 0

Table 5. History of bullfrog (BF) sightings and related survey effort at the Waterfowl Ponds.

Date	Observation
26 May 1995	12 BF seen in Pond 5 - the only pond with water. 1 BF calling during the day.
Fall 1995	All ponds dried up.
31 May 1996	Ponds 1, 2, 4, & 5 had some water. BF absent, RLF present continuously from this time onward.
Winter 1996 - summer 1997	Frequent, extensive surveys confirm the continued absence of BF.
20 November 1997	Juvenile (52 mm SUL) BF removed from Pond 5.
Winter 1997/1998	6 survey nights - no BF detected. Night surveys not conducted again until August 1998.
July 1998	BF heard calling on several days. 1 BF called from Pond 2, and 2-3 from Pond 4. 2 subadult BF seen in Pond 4. No BF larvae caught in tadpole traps.
August 1998	3 - 4 BF calling at night in Pond 4. Only portions of Pond 4 were surveyed - 1 to 2 BF seen during 2 surveys. BF not heard calling or seen in Pond 5. No surveys from September 1998 through May 1999.
20 June - 26 September 1999	Rebecca Doubledee's study of BF's in Pond 4. Maximum number of BF seen during 1 night survey was 6 adults and 1 subadult. BF started calling early July. No BF larvae caught in tadpole traps.
August - September 1999	Several night surveys of Ponds 4 & 5. Maximum number of BF seen during 1 survey was 8. All BF were in Pond 4 and none seen in Pond 5.
May - early June 2000	Several day and night surveys - BF not calling yet at WF ponds, even though they were at inland sites.
17 June 2000	Freshly-laid BF egg mass found in Pond 4. 4 subsequent surveys performed at weekly intervals did not detect other BF egg masses, and BF were not calling during the day.
August - September 2000	4 night surveys at Ponds 4 & 5. Maximum number of BF seen were 3 adults in Pond 4, 1 adult in Pond 5, and 1 adult calling infrequently in Pond 4.

Table 6. Comparison of water temperature measured at Ponds 4 and 5 of the Waterfowl Ponds between other sites on Vandenberg Air Force Base. Pine Canyon has a well-established population of bullfrogs, Mod III and Pond 4 have a low density of bullfrogs, and Pond 5 has a very low density of bullfrogs. Data are mean temperature in °C (number of measurements) and range.

	0.1 m deep	1.0 m deep
Pine Canyon - Lower	22.5 (8) 21.5 - 23.5	23.0 (8) 22.0 - 24.0
Pine Canyon - Middle	22.1 (4) 22.0 - 22.5	22.9 (4) 22.5 - 23.0
Mod III	20.9 (4) 20.0 - 21.5	21.5 (4) 21.0 - 22.0
Pond 4	20.4 (32) 18.5 - 23.5	20.4 (32) 19.0 - 22.0
Pond 5	18.5 (32) 17.0 - 22.0	19.1 (32) 17.0 - 20.0

Table 7. Species of amphibians and reptiles observed at the Waterfowl Ponds. Nomenclature follows Collins (1997).

CAUDATA - SALAMANDERS

<i>Batrachoseps nigriventris</i>	Blackbelly slender salamander
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ANURA - FROGS

<i>Hyla regilla</i>	Pacific treefrog
<i>Rana aurora draytonii</i>	California red-legged frog
<i>Rana catesbeiana</i>	Bullfrog

TESTUDINES - TURTLES

<i>Clemmys marmorata pallida</i>	Southwestern pond turtle
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LACERTILIA - LIZARDS

<i>Elgaria multicarinata multicarinata</i>	California alligator lizard
<i>Sceloporus occidentalis</i>	Western fence lizard
<i>Uta stansburiana elegans</i>	California side-blotched lizard

SERPENTES - SNAKES

<i>Coluber mormon</i>	Western racer
<i>Lampropeltis getula californiae</i>	California kingsnake
<i>Pituophis melanoleucus</i>	Gopher snake
<i>Thamnophis elegans terrestris</i>	Coast garter snake
<i>Thamnophis sirtalis infernalis</i>	California red-sided garter snake

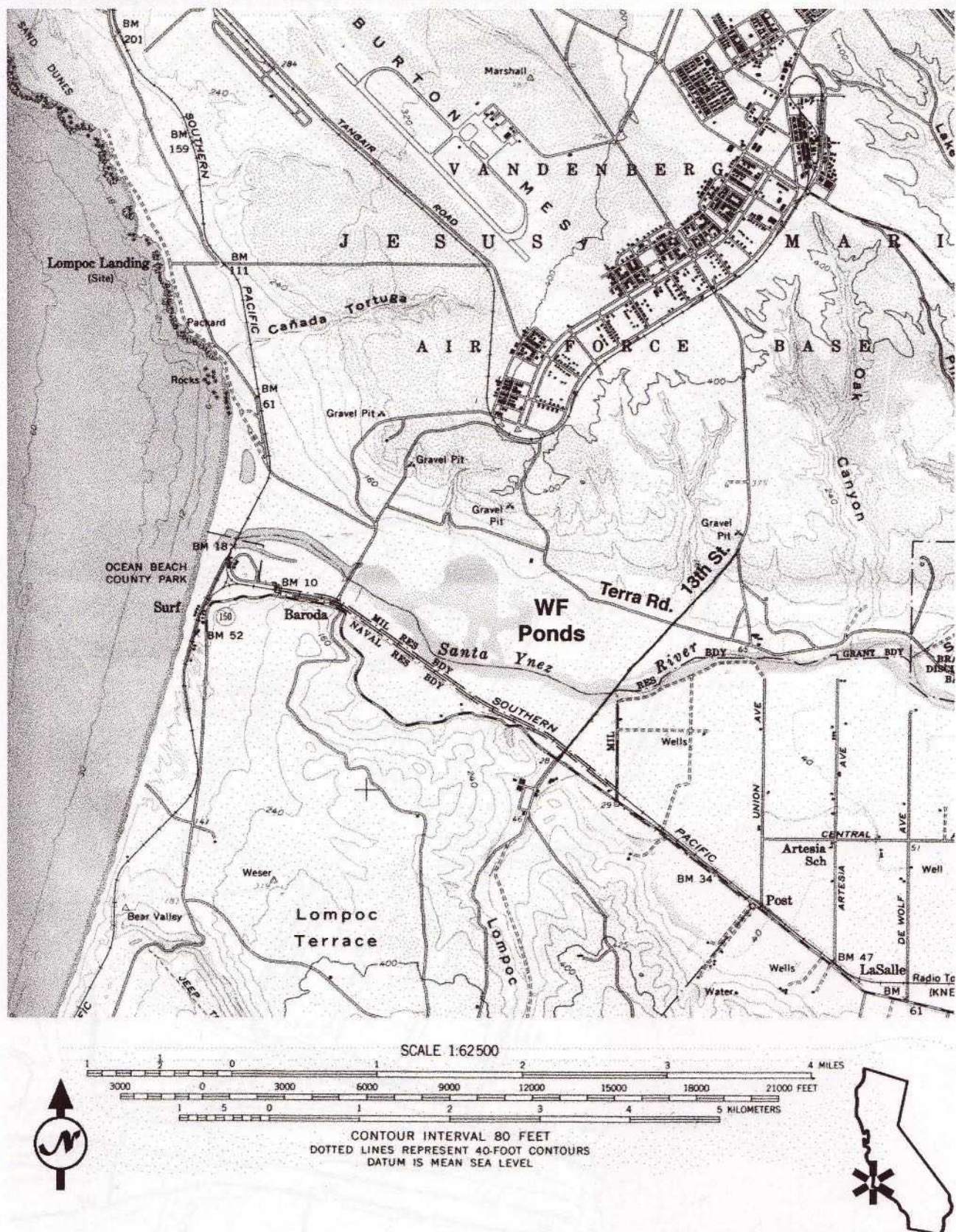


Figure 1. Area map of the Waterfowl Ponds. Adapted from U. S. G. S. Point Arguello, Calif. 15' quadrangle.

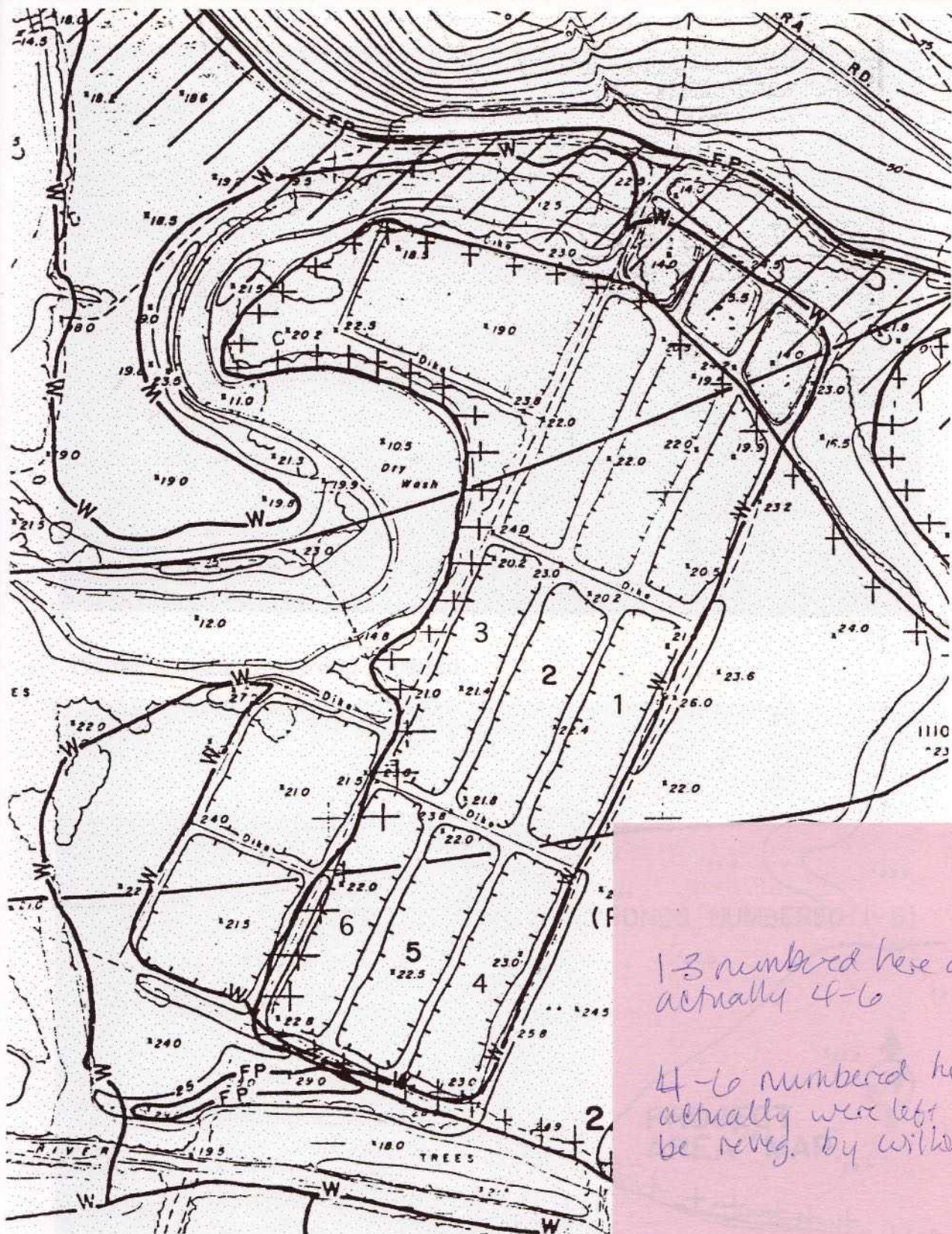


Figure 2. Site map of the Waterfowl Ponds. Adapted from McElligott (1989).



Figure 3. Waterfowl Pond 1 habitat.



Figure 4. Waterfowl Pond 2 habitat.



Figure 5. Waterfowl Pond 4 habitat.



Figure 6. Waterfowl Pond 5 habitat.



Figure 7. Variation in color of the California red-legged frog.

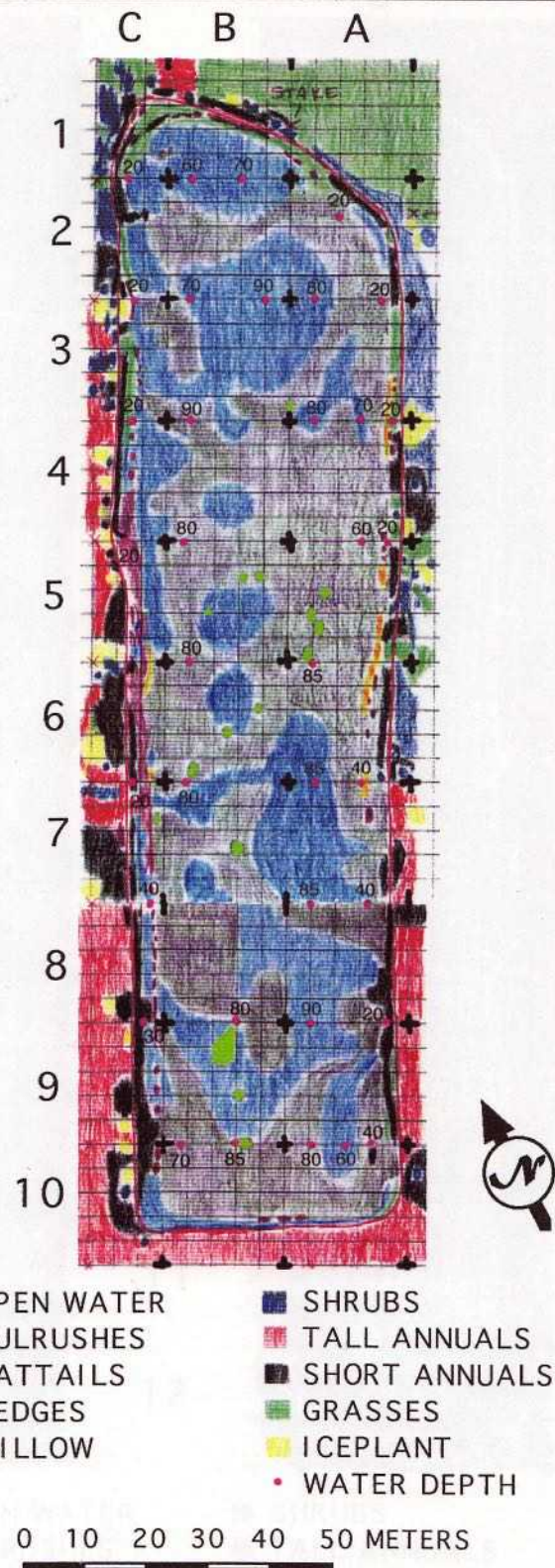


Figure 8. Habitat map of Pond 1, drawn in November 1996.

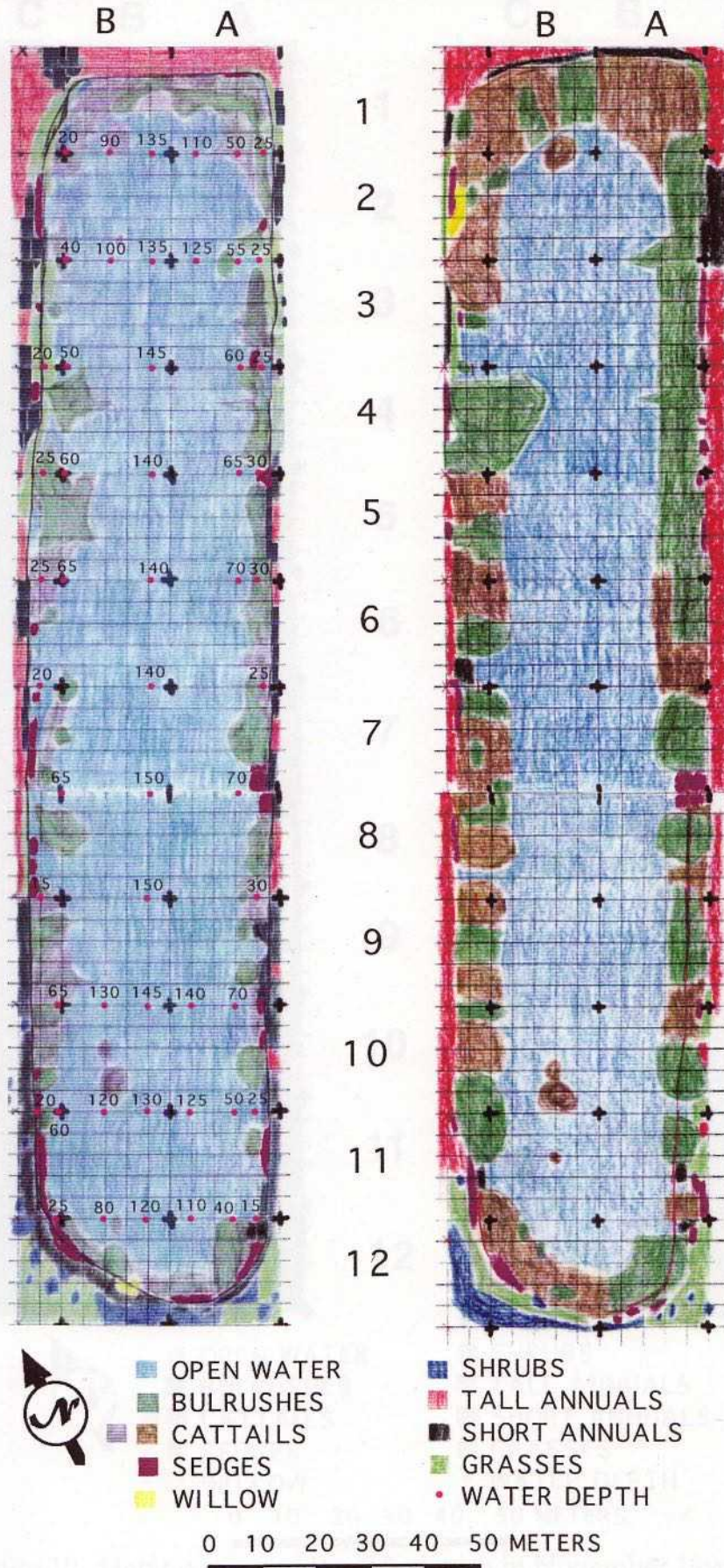


Figure 9. Habitat maps of Pond 4, drawn in November 1996 (left) and August 1997 (right).

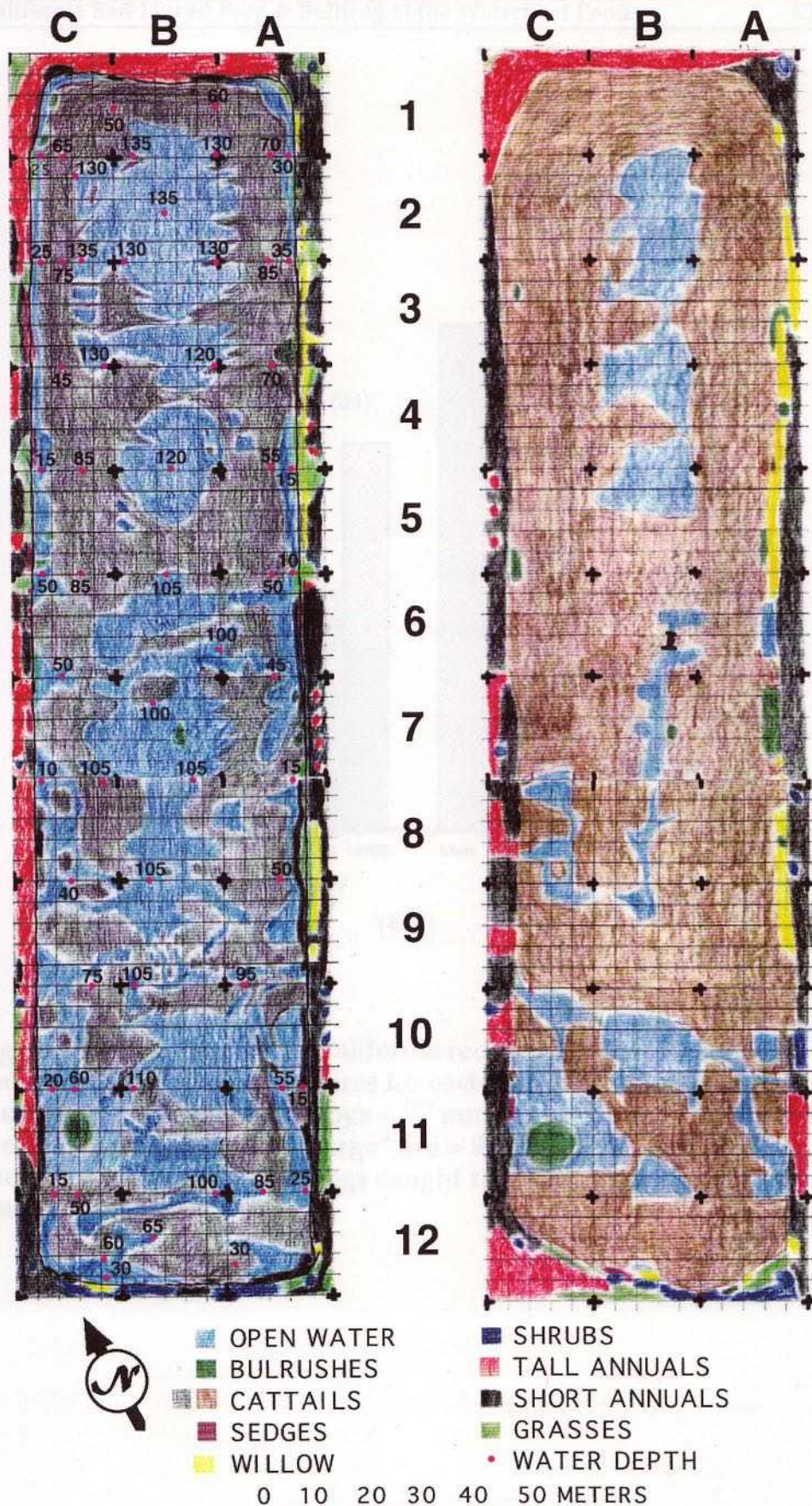


Figure 10. Habitat maps of Pond 5, drawn in November 1996 (left) and August 1997 (right).

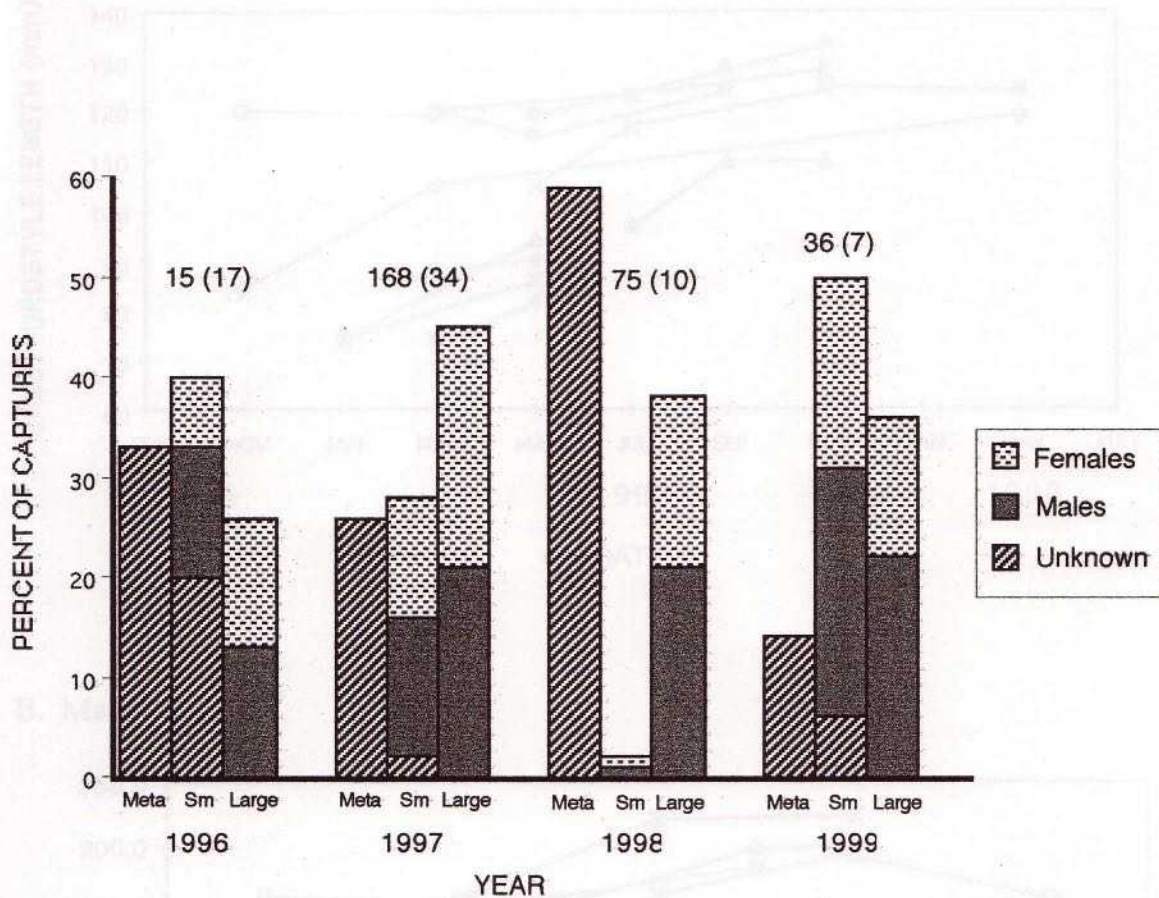
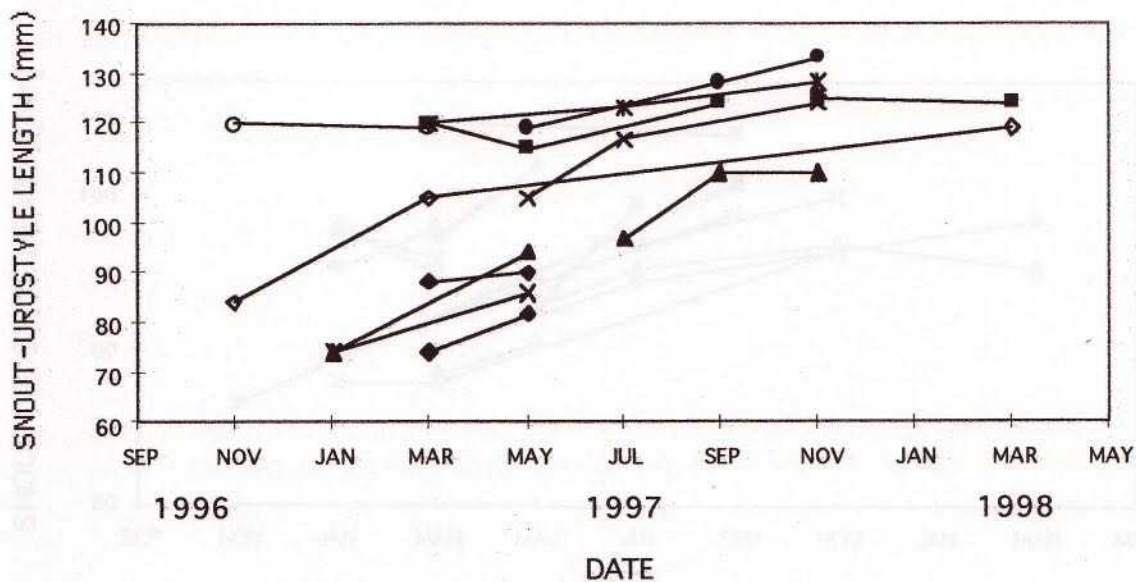


Figure 11. Demography of California red-legged frog captures by year. Bars show the percentage of captures for each year by sex and size class. "Meta" are recently-metamorphosed frogs < 57 mm snout-urostyle length (SUL); "Sm" are 57 - 90 mm SUL; and "Large" are > 90 SUL. The numbers above the bars show the total number of frogs caught that year (number of times each pond was surveyed).

Figure 12. Growth of female California red-legged frogs that were marked and recaptured.

A. Length



B. Mass

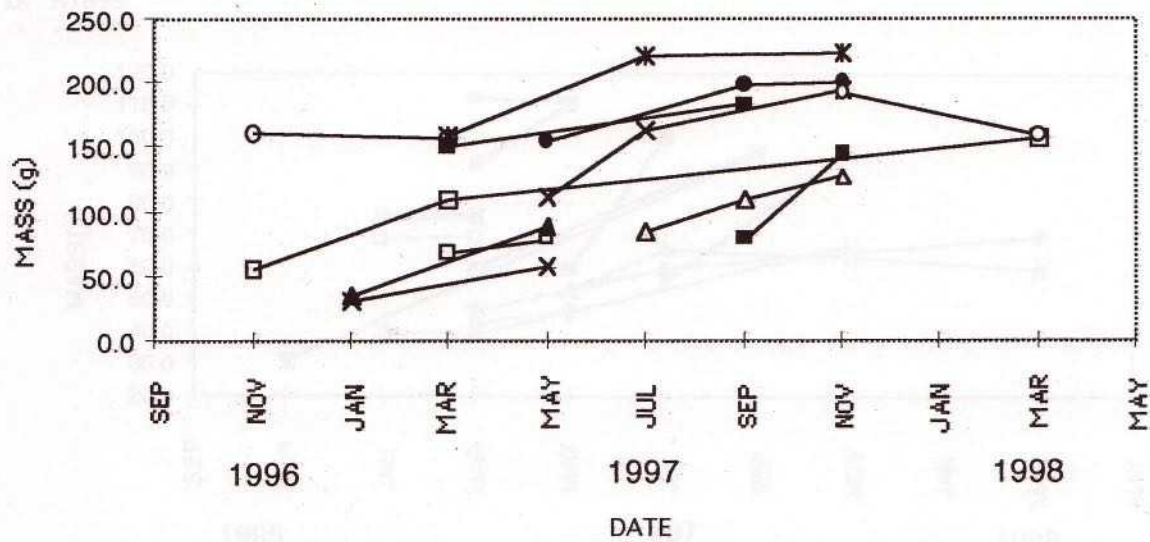
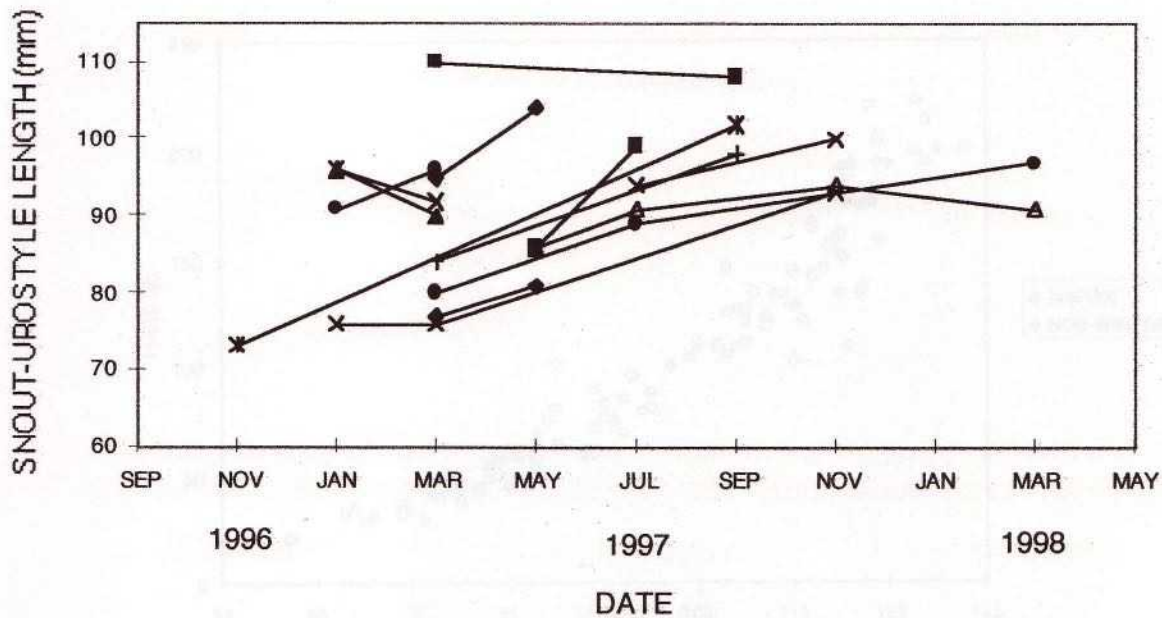


Figure 12. Growth of female California red-legged frogs that were marked and recaptured.

A. Length



B. Mass

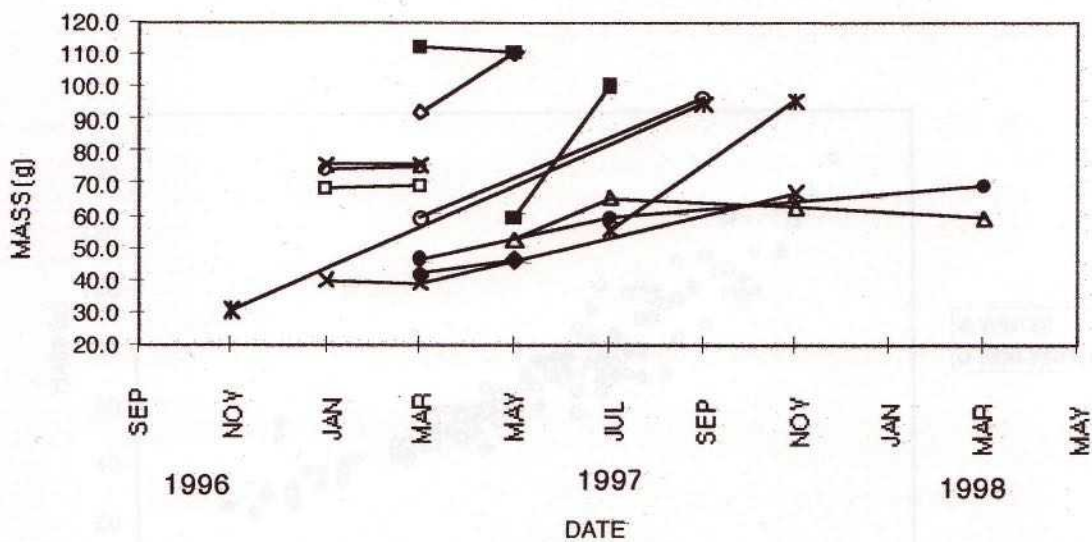
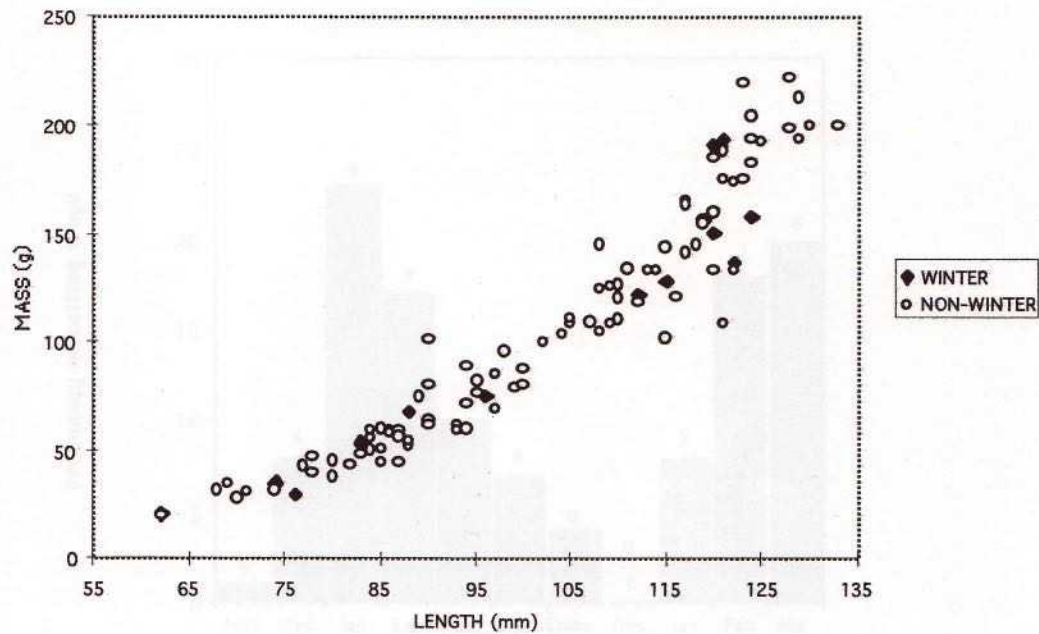


Figure 13. Growth of male California red-legged frogs that were marked and recaptured.

Figure 14. Mass of California red-legged frogs by length measured in winter (14 December - 2 March) compared to frogs caught in all other times of year.

A. Females



B. Males

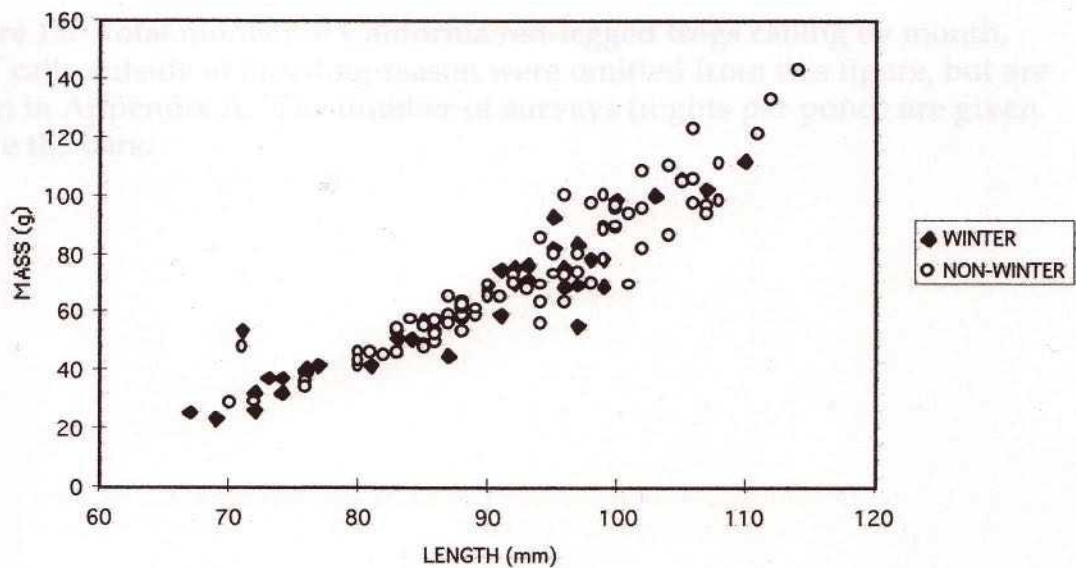


Figure 14. Mass of California red-legged frogs by length, measured in winter (14 December - 2 March) compared to frogs caught in all other times of year.

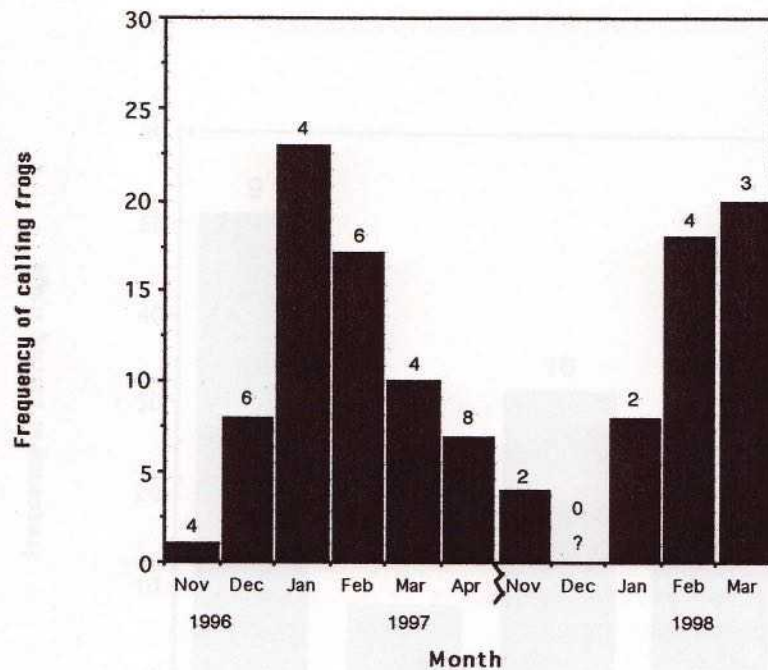


Figure 15. Total number of California red-legged frogs calling by month. Brief calls outside of breeding season were omitted from this figure, but are given in Appendix A. The number of surveys (nights per pond) are given above the bars.

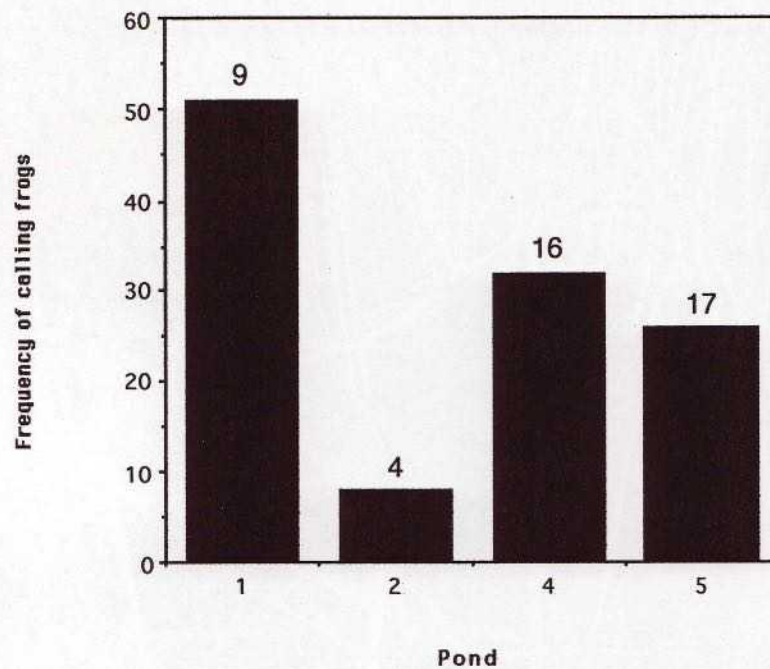


Figure 16. Total number of California red-legged frogs heard calling at each of the Waterfowl Ponds. Brief calls heard outside of the breeding season were omitted. The number of surveys conducted during breeding season is given above the bars.



Figure 17. Typical calling site of a male California red-legged frog in Pond 1.

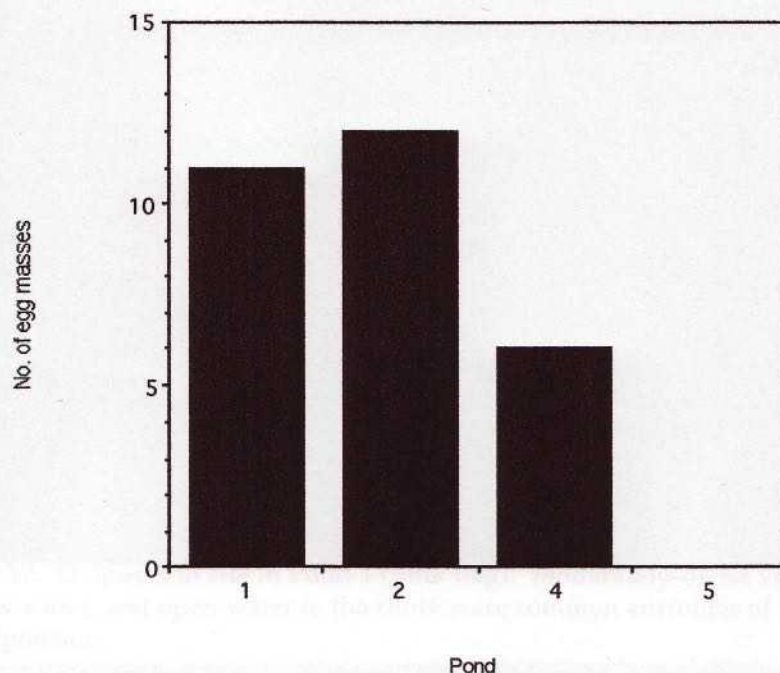


Figure 18. Total number of California red-legged frog egg masses found at the Waterfowl Ponds in winter 1998. Each pond was searched completely three times during breeding season. In 1997, 10 egg masses were found in Pond 5.



Figure 19. Oviposition site in Pond 1 (pink flag). Moderately-dense vegetation, relatively shallow water, and open water to the shore were common attributes of the microhabitat used for oviposition.



Figure 20. Oviposition sites in Pond 4 (3 pink flags at the edge of the emergent vegetation). This type of microhabitat was only present in the winter when precipitation increased the water levels of the pond, and flooded areas that were usually vegetated by short, relatively-sparse upland species.

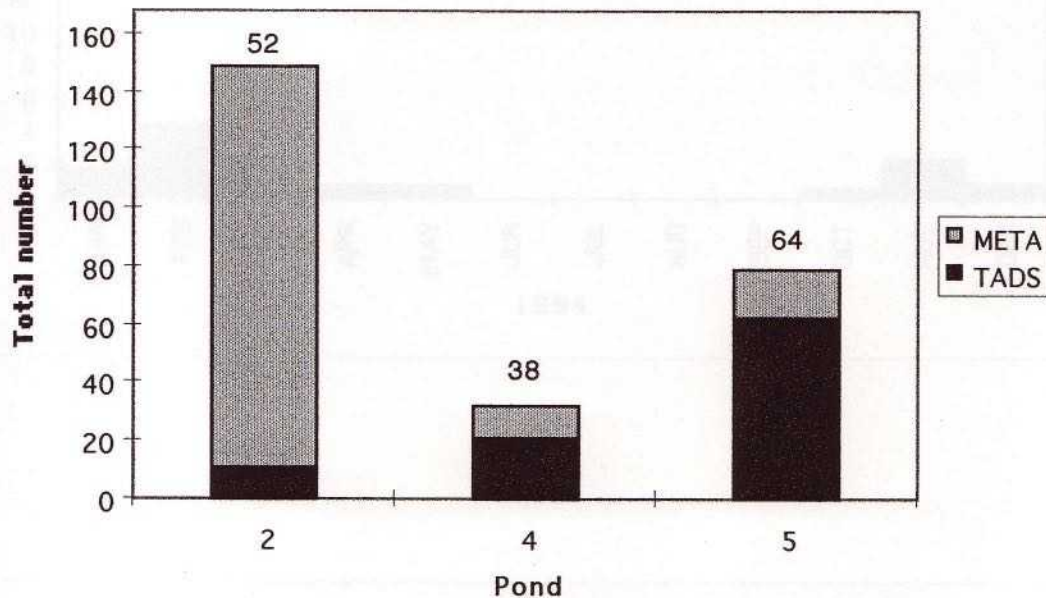


Figure 21. Ratio of California red-legged frog tadpoles and metamorphs trapped at three Waterfowl Ponds from 15 July through 13 August 1998. Numbers above the bars indicate the trapping effort (traps*days). All traps were set in similar types of microhabitats.

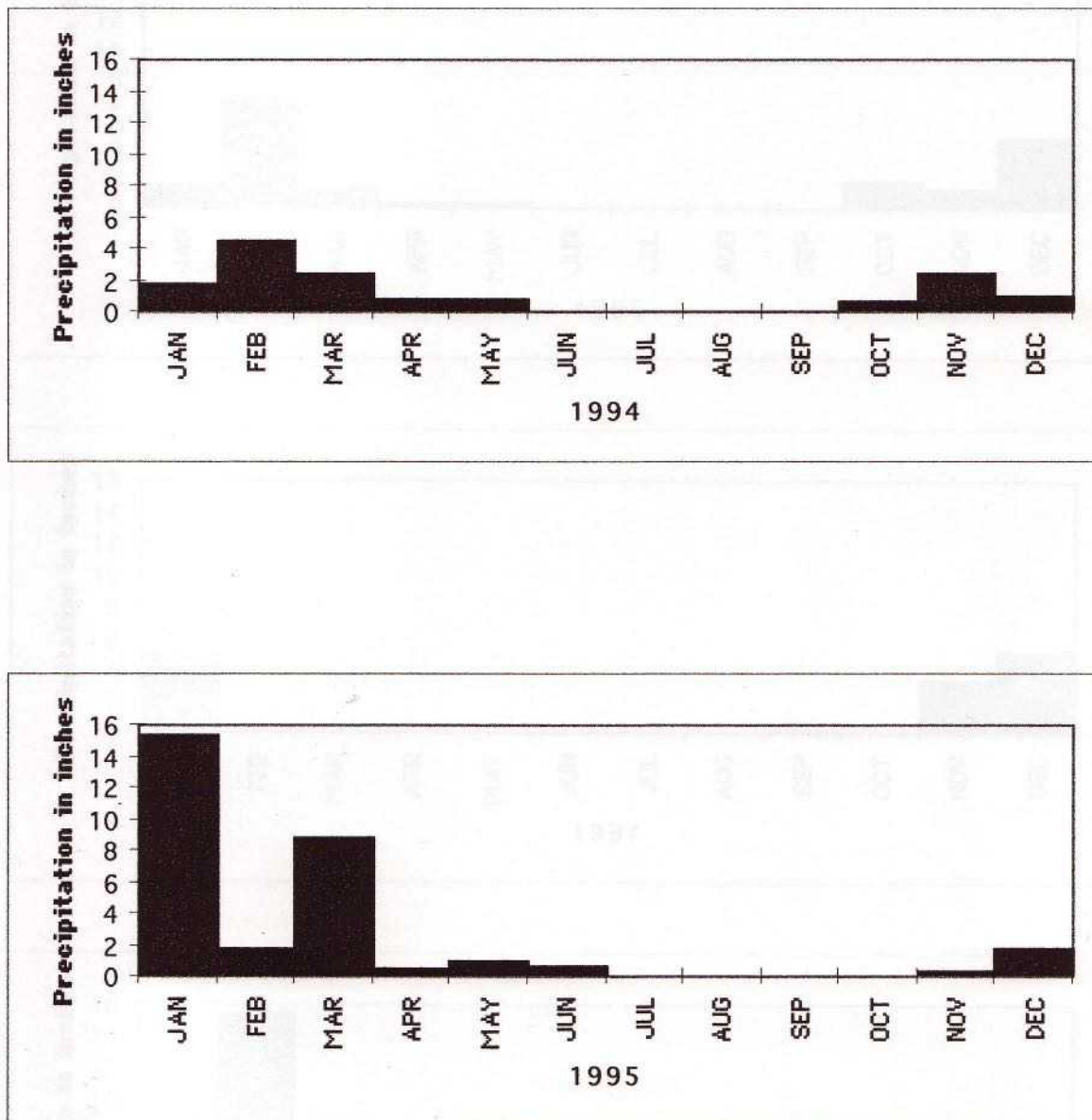


Figure 22. Monthly precipitation recorded at Lompoc, California. Source: Western Regional Climate Center [www.wrcc.dri.edu/index.html].

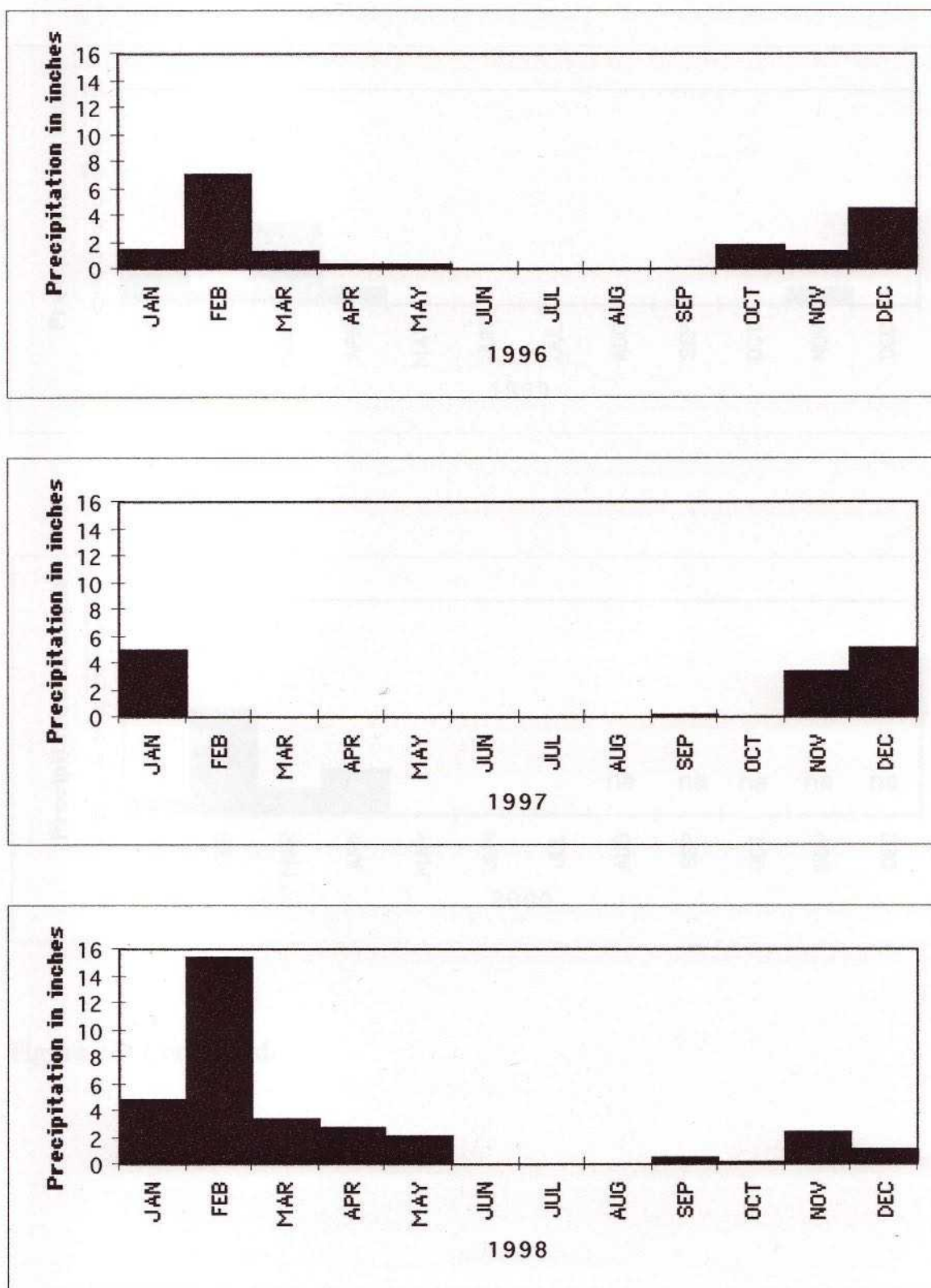


Figure 22. Continued.

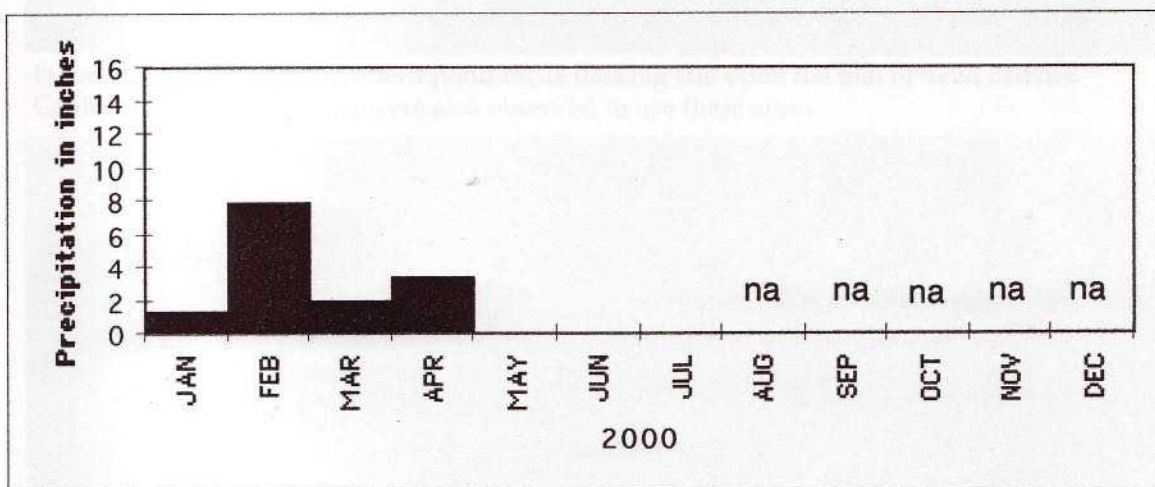
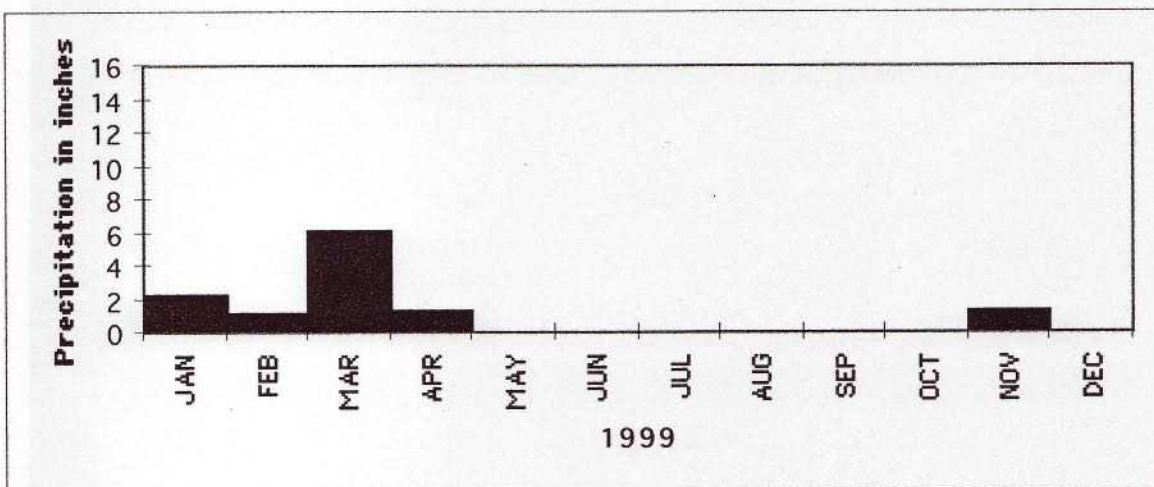


Figure 22. Continued.



Figure 23. Typical southwestern pond turtle basking site upon the mat of dead cattails. California red-legged frogs were also observed to use these areas.



Figure 24. Dense patches of cattails adjacent to open water were favored by California red-legged frogs in Pond 5. Dense mats formed by a collapsed bunch of cattails were used by several radio-tagged frogs throughout the winter months (Christopher, unpublished data), and probably offer suitable refugia from most predators.



Figure 25. Clumps of cattails become uprooted and float to the surface, making an ideal spot for California red-legged frogs to sit upon. Bulrushes do not produce these "frog islands".