Arnold Schwarzenegger
Governor

IDENTIFYING MICROCLIMATIC AND WATER FLOW TRIGGERS ASSOCIATED WITH BREEDING ACTIVITIES OF A FOOTHILL YELLOW-LEGGED FROG *(Rana boylii)* POPULATION ON THE NORTH FORK FEATHER RIVER, CALIFORNIA

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
Garcia and Associates (GANDA)

January 2008
CEC-500-2007-041

Prepared By:
Garcia and Associates (GANDA)
Joseph E. Drennan, Ronald E. Jackman,
Karla R. Marlow, Kevin D. Wiseman
2601 Mission Street, Suite 600
San Francisco, CA 94110

Commission Contract 500-01-044

Prepared For:
Public Interest Energy Research (PIER) Program
California Energy Commission

Joe O'Hagan
Contract Manager

Kelly Birkinshaw
Program Area Lead
Energy-Related Environmental Research

Ken Koyama
Acting Office Manager
Energy Systems Research

Martha Krebs
Deputy Director
ENERGY RESEARCH & DEVELOPMENT DIVISION

Melissa Jones
Acting Executive Director

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

Acknowledgments

The authors wish to acknowledge several individuals for their role in supporting this research. The Pulsed Flow Program managers from the University of California (UC) Davis Center for Aquatic Biology and Aquaculture, Paciencia Young and Douglas Conklin, provided thoughtful input into the study plan and provided suggestions on presenting the results. Jim Canaday at the State Water Resources Control Board and Carson Cox at California Department of Fish and Game reviewed the study plan and offered constructive criticism. The authors thank Craig Seltenrich for supporting the early work on the North Fork Feather River and for his efforts to increase awareness of the foothill yellow-legged frog. The authors also extend thanks to PG&E employees for their support of this effort, especially Christopher Herrala, Alicia Pool, Andrea Herman, Michael Carbiener, Stuart Moock, Stuart Running, Paul Kubicek, and Charlie White. The authors also thank amphibian biologists Amy Lind and Sarah Kupferberg for their critical review of the interim report and for providing recommendations to improve this final report. In addition, the authors thank colleagues Becky Parker, Wendy Roberts, Jason Minton, and Jane Kim for their assistance during the project. Finally, the authors thank John and Carole Garcia for their technical and financial support of this project.

Please cite this report as follows:

Garcia and Associates (GANDA). 2008. *Identifying Microclimatic and Water Flow Triggers Associated with Breeding Activities of a Foothill Yellow-Legged Frog* (Rana boylii) *Population on the North Fork Feather River, California.* California Energy Commission, PIER Energy-Related Environmental Research Program. CEC-500-2007-041.

Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Identifying Microclimatic and Water Flow Triggers Associated with Breeding Activities of a Foothill Yellow-Legged Frog (Rana boylii) *Population on the North Fork Feather River, California* is the final report for the Ecological Impacts of Pulsed Flows from Hydroelectric Facilities program (contract 500-01-044 conducted by Garcia and Associates (GANDA). The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier or contact the Energy Commission at 916-654-5164.

Table of Contents

Preface iii

Abstract ix

Executive Summary 1

1.0 Introduction 3

1.1. Background and Overview 3

1.2. Project Objectives 4

1.3. Report Organization 4

2.0 Methods 5

2.1. Study Area 5

2.2. Frog Surveys 5

2.2.1. Visual Encounter Surveys 5

2.2.2. Radio Telemetry 9

2.3. Environmental Data 10

2.4. Data Analysis 10

2.4.1. Individual Frog Identification 10

2.4.2. Determination of Frog Movement and Breeding Activity 11

2.4.3. Statistical Analysis 13

3.0 Results 17

3.1. General Characteristics of Foothill Yellow-legged Frogs on the Poe and Cresta Reaches 17

3.1.1. Number of Frogs 17

3.1.2. Sizes of Frogs 18

3.1.3. Location and Activity of Frogs 18

3.1.4. Frog Breeding Loci 20

3.1.5. Staging at Breeding Sites 20

3.1.6. Movement Rates 22

3.2. Environmental Conditions 23

3.3. Initial Movements 25

3.3.1. Between-year Comparison of Initial Movements 26

3.3.2. Comparison to Conditions Five Days Prior to Initial Movements 27

3.4. Breeding 28

3.4.1. Between-year Comparison of Breeding 28
3.4.2. Comparison to Conditions Five Days Prior to Breeding 29
3.4.3. Logistic Regression 31
3.4.4. Alternative Breeding Cues 32
3.5. Intertributary Movements 33
3.6. Culverts 33
4.0 Conclusions and Recommendations 35
4.1. Conclusions 35
4.2. Commercialization Potential 36
4.3. Recommendations 37
4.4. Benefits to California 37
5.0 References 39
6.0 Glossary 41

Appendix A. Tributary Descriptions

Appendix B. Photographs of Representative Frog Activities, Locations, Habitat, and Chin patterns

List of Figures

Figure 1. Cresta Reach tributary and breeding sites..... 7

Figure 2. Poe Reach tributary and breeding sites 8

Figure 3. Adult female foothill yellow-legged frog captured on April 28, 2004, (top photograph) and the same frog recaptured on March 22, 2005 12

Figure 4. Location (N=678) and activity (N=735) categories for frog observations during 2004 and 2005, excluding radio-tagged frogs 19

Figure 5. Location (N =535) and activity (N =485) categories for radio-tagged frogs observed during 2005..... 19

Figure 6. Cresta Reach hydrograph and breeding dates in 2004 (bottom, foreground) and 2005 (top, background). Round circles represent individual egg masses laid on those days..... 24

Figure 7. Poe Reach hydrograph and breeding dates in 2004 (bottom, foreground) and 2005 (top, background). Round circles represent individual egg masses laid on those days..... 24

Figure 8. Environmental variables associated with initial movement and breeding dates of frogs on Flea Valley Creek in 2005. Arrows indicate the range (endpoints) and mean dates (open circles) of initial movements for male and female frogs. Stacked bars indicate the numbers of egg masses laid at the breeding sites associated with Flea Valley Creek. 25

Figure 9. Mean mainstem temperatures and percent above mainstem base flow on estimated breeding dates (N=132) in the Poe and Cresta reaches during 2004 and 2005. Dot size reflects the number of occurrences. Outliers beyond 100% above base flow include 2 Poe Reach and 4 Cresta Reach breeding dates from 2005. 30

Figure 10. Breeding dates of female frogs of known weight from Tributary 6c on the Poe Reach in 2005..... 32

List of Tables

Table 1. Summary of recapture data for the Cresta and Poe reaches of the North Fork Feather River during 2004 and 2005 17

Table 2. Summary of radio-tagged frogs for the Cresta and Poe reaches of the North Fork Feather River during 2005 18

Table 3. Mean weight and snout-to-urostyle length (and range) of adult male and female frogs 18

Table 4. Minimum number of days that frogs were present at mainstem breeding sites and sex ratio for each tributary and reach during 2004 and 2005. Data are divided according to tributary of origin, reach, and combined reaches. 21

Table 5. Minimum number of days that male frogs observed greater than one time were observed at mainstem breeding sites for each tributary in 2004, 2005, and both years combined. Data are divided according to tributary of origin and reach. Standard deviation and range are provided for those cells where N > 3. 21

Table 6. Minimum mean daily rate of frog movement during 2004 and 2005 22

Table 7. Initial movement date for Poe Reach males in 2005 and associated tributary water temperature, air temperature, and precipitation recorded. No initial movement data was obtained for Cresta males in both years, and none were obtained for Poe males in 2004. 26

Table 8. Mean date, tributary water and regional air temperature, and 10-day accumulated precipitation recorded when female frogs initiated movements from tributaries to mainstem river breeding sites in 2004 and 2005 27

Table 9. Difference between tributary water and air temperature, and five-day accumulated precipitation recorded when female frogs initiated movements from tributaries to mainstem river breeding sites and conditions five days prior 28

Table 10. Mean breeding date, mainstem flow, and water temperature when frogs bred during 2004 and 2005 29

Table 11. Difference between mainstem water temperature and flow level recorded when frogs breed and conditions five days prior 30

Table 12. Cresta and Poe Reach Female Logistic Regression Effect Tests 31

Abstract

Using visual surveys and radio telemetry, researchers monitored movements and breeding activities of a population of foothill yellow-legged frogs (*Rana boylii*) to determine their relationship to climatic variables in six tributaries and their associated breeding sites on the Poe and Cresta reaches of the North Fork Feather River (NFFR) during spring in 2004 and 2005. Male frogs left tributaries earlier than females and stayed longer at breeding sites. Breeding areas were located along the mainstem river adjacent to the tributaries, and the frogs lived around the tributaries for most of the year. Time of year was the only parameter statistically correlated with initial movements in females. In late April/early May, when mean daily tributary temperatures were ≥ 10°C (≥ 50°F), females left home ranges on tributaries to breed on the NFFR. Most of the frogs laid eggs when mean mainstem temperatures were between 10°C (≥ 50°F) and 16°C (≥ 61°F), and mainstem flow was between baseflow and less than 55 percent above baseflow. Length of stay by females at river breeding sites was extended by high flows and, on the Cresta Reach, relatively low numbers of males. Late season rains and associated high flows delayed breeding in 2005. Based on the model of environmental parameters affecting breeding activity, this study provides hydroelectric power managers information (such as movement dates, temperature, and flow preferences) to enhance foothill yellow-legged frog breeding success by preventing sharp fluctuations in the water levels during the breeding season from April through June.

Keywords: Breeding, foothill yellow-legged frog, movement ecology, oviposition, pulse flows, *Rana boylii*

Executive Summary

Introduction

The foothill yellow-legged frog (*Rana boylii*) inhabits streams and rivers from Oregon and California and has experienced drastic population declines in some parts of its range. Due to the dynamic nature of river discharge levels, the frogs must select an egg-laying site that prevents their eggs from drying out if flows drop significantly during egg development and prevents their eggs from being washed away if late-season precipitation or unseasonable warming accelerates snowmelt, thereby increasing stream flow strength. The current practice of releasing pulse flows from dams to mimic the natural water flow over time, for channel maintenance or whitewater boating recreation, could be inappropriately timed for foothill yellow-legged frogs, and it could present the danger of egg mass scouring or displacement of small-sized tadpoles in early development.

Purpose

Water-release decisions that optimize hydroelectric power generation in river systems while conserving the foothill yellow-legged frog populations that inhabit these systems can be complex. This study was designed to provide hydroelectric power operators with a model that could predict when frogs breed, to minimize negative impacts to these populations.

Project Objectives

This study's primary objectives were to determine:

- How local environmental conditions (such as water temperature, stream flow, and precipitation) affect the onset of foothill yellow-legged frog breeding activities; specifically,
    - (a) Initial movement from tributaries to river breeding sites.
    - (b) Breeding dates.
- How pulse flows and irregular flow releases associated with high runoff and regulated rivers affect the breeding and movement patterns of adult frogs.

This study's secondary objectives were to determine:

- How adult foothill yellow-legged frogs use tributaries as movement corridors during the pre-breeding period.
- How culverts affect foothill yellow-legged frog movements.

Project Outcomes

A total of 476 individual adult frogs were identified during the study, with 47 frogs captured in both years. In 2005, 46 female and 6 male frogs were radio-tagged and tracked from initial movement periods to post-breeding. Frogs were most often observed in the stream channel, usually basking. Male frogs initiated movement to the river before females in both years. The mean date of initial movement to mainstem breeding sites for Cresta Reach females was on May 9 in 2004 and on May 5 in 2005. Poe Reach females' mean date of initial movement was on May 4 in each year. Rate of movement for female frogs (58.1 meters per day) was about twice as fast as male frogs. The longest movement was observed in a female frog, which covered a distance of at least 1899 meters in ≤ 6 days, for a minimum mean movement rate of 316.5 meters per day. In general, male frogs were present at mainstem river breeding sites earlier than females and remained for longer durations. Once at the river, most frogs laid eggs when river temperatures were ≥ 10°C (≥ 50°F) and river flow was ≤ 55 percent of baseflow and on the descending limb of the hydrograph.

Conclusions

Based on this study's results, the researchers reached the following conclusions:

- Observations of radio-tagged frogs during high flows in 2005 provided evidence that most frogs are able to tolerate high flows and not get washed downstream or otherwise harmed.
- High flows during the early breeding season, natural or manufactured, apparently do not affect the timing of initial frog movements to mainstem river breeding areas.
- Initial movements to the river are triggered by day length, but the date when frogs lay eggs is a function of mainstem temperature and flow level.
- The timing of breeding is influenced by the interaction of three variables: temperature, water flow, and day length.

Recommendations

These data suggest that hydroelectric facility managers could extend the declining limb of spring pulse flows in a manner that would prevent rapid changes in river discharge, as a conservation measure to increase breeding success in foothill yellow-legged frogs.

Benefits to California

These research results provide critical information about foothill yellow-legged frog movement and breeding patterns and how they are affected by environmental parameters. This information will enable hydroelectric power managers to enhance the breeding success of this California Species of Special Concern, and provide information to resource agencies and stakeholders involved in the relicensing process for hydroelectric power projects in California.

1.0 Introduction

1.1. Background and Overview

The foothill yellow-legged frog *(Rana boylii)* inhabits streams and rivers from coastal Oregon south into coastal California and west of the Sierran crest from sea level to approximately 2040 meters (m) (6700 feet [ft]) (Stebbins 2003). In California, it is listed as a Species of Special Concern, has undergone a drastic range reduction, and is extinct in numerous historic localities in the southern Sierra Nevada Mountains (Jennings and Hayes 1994; Stebbins 2003). At-risk populations of foothill yellow-legged frog currently exist in regulated river drainages in northern California including the Pit, Feather, and Yuba rivers. As such, determining better, cost effective means of protecting these populations is of importance to hydroelectric power managers.

Typical foothill yellow-legged frog habitat consists of cobble bars along stream or river margins with various amounts of boulder, cobble, gravel, and vegetation (Ashton et al. 1998; Yarnell 2000). On the North Fork Feather River (NFFR), adult frogs are typically found on mainstem river margins only during the breeding season from March to June, and usually retreat into shaded tributaries during mid-summer where they remain until the following spring (GANDA 2003a; GANDA 2003b; GANDA 2005). Females attach a single mass of approximately 300–1000 eggs to a rocky substrate in slow-to-moderately flowing (< 20 centimeters per second [cm/sec]) edgewater habitats.

The environmental triggers affecting the timing of foothill yellow-legged frog breeding are not known. A number of factors may influence the timing of amphibian breeding, including temperature and day length (Duellman and Trueb 1986). The seasonal timing of precipitation and associated stream flow volume may affect the timing and location of oviposition in certain stream-breeding frogs (Fukuyama and Kusano 1992). On the South Fork Eel River in northern California, oviposition occurred earlier in low base-flow discharge years compared to high base-flow discharge years, and the duration of the oviposition period was extended during rainy years (Kupferberg 1996). The same study also found that oviposition appeared to begin after water temperatures reached 12°C. However, foothill yellow-legged frog eggs have been documented in water with temperatures ranging from 9°C to 21.5°C (Zweifel 1955). On the Poe Reach of the NFFR (regulated reach below Poe Dam), mean water temperature when egg masses were first located during 2001–2003 was 17.1°C (Range 12°C–28°C; standard deviation [SD] 3.3) (GANDA 2003a). On the Cresta Reach of the NFFR (the regulated reach below Cresta Dam), mean water temperature when egg masses were first located during 2002–2004 was 16.8°C (Range 14.4°C–19.0°C; SD 1.2; GANDA 2005). However, these temperatures were recorded when egg masses were first discovered and do not necessarily reflect temperatures at the time of oviposition. On both the Cresta and Poe reaches during these earlier studies, all egg masses were found while the river was at base flow level (~220 cubic feet per second [cfs] on the Cresta Reach and ~110 cfs on the Poe Reach).

Due to the dynamic nature of river discharge levels, selection of oviposition site is critical to avoid desiccation if flows drop significantly during egg development, or conversely, to avoid scouring and detachment of egg masses if late-season precipitation or unseasonable warming accelerates snowmelt thereby increasing stream discharge (Kupferberg 1996). These concerns are even more complicated along regulated rivers, where efforts by hydroelectric power or irrigation water managers to store and maximize utilization of water resources may be overwhelmed by these late-season weather events and may produce unexpectedly high discharges into river reaches below dams (Lind et al. 1996). In addition, the current practice (including on the NFFR) of releasing pulse flows from dams to mimic the natural hydrograph, for channel maintenance, or for whitewater boating recreation, could be inappropriately timed for foothill yellow-legged frogs and present the danger of egg mass scouring or displacement of small-sized tadpoles in early development.

1.2. Project Objectives

This study addresses four general questions: two primary and two secondary. Primary objectives addressed by this study were:

1. To identify how local environmental conditions (e.g., water temperature, stream flow, precipitation) affect the onset of foothill yellow-legged frog breeding activities, specifically,
    a. initial movement from tributary refugia to river breeding sites, and
    b. the date of breeding.
2. To assess how pulse flows and irregular flow releases associated with high runoff and regulated rivers affect the breeding and movement patterns of adult frogs.

Secondary objectives addressed by this study were:

1. To determine how adult foothill yellow-legged frogs use tributaries as movement corridors during the pre-breeding period; and,
2. To determine how culverts affect foothill yellow-legged frog movements.

1.3. Report Organization

The remainder of this report includes the study methods (Section 2.0), results (Section 3.0), conclusions and recommendations (Section 4.0), references (Section 5.0), and two appendices. Appendix A provides a detailed description of each study tributary, and Appendix B provides representative photographs recorded during the study.

2.0 Methods

Frog activities and environmental variables were monitored during the breeding season in 2004 and 2005 in an effort to determine the environmental triggers for breeding. Frog locations and sexual condition (gravid, or spent [i.e., eggs laid]) were recorded during repeated surveys to determine initial movement and breeding dates. In 2004, visual encounter surveys were used exclusively, but in 2005 radio telemetry was added to increase sample size and improve the ability to relocate frogs. At the same time that surveys were conducted, data on environmental variables with potential to affect frog behavior was collected, including tributary temperature, tributary stage height, air temperature, precipitation, mainstem temperature, and mainstem flow levels.

2.1. Study Area

The study area includes the Poe and Cresta reaches of the NFFR (Figures 1 and 2). Both of these reaches have flows controlled by hydroelectric dams and are required to maintain specific base flow levels as stipulated by their Federal Energy Regulatory Commission (FERC) license agreements, although they may provide flows at levels above the required minimum. Currently, the Cresta Reach is maintained at ~220 cubic feet per second (cfs) and the Poe Reach is maintained at ~110 cfs. Since 2002, the Cresta Reach has also provided recreational flows for whitewater boating. These flows have occurred one day per month during June through October, with flow levels maintained at ~1,000 to 1,200 cfs for approximately six hours.

The study area also includes six tributary streams to the North Fork Feather River. The surveyed portion of these tributaries ranged in length from 248 to 1454 m. Elevations ranged from 275 m (902 ft) at the downstream end of the project area to 562 m (1843 ft) at the top end of Tributary 6c. Appendix A provides detailed descriptions of each tributary.

2.2. Frog Surveys

2.2.1. Visual Encounter Surveys

Visual encounter surveys were conducted for foothill yellow-legged frogs from April 13 to June 11, 2004, and from February 14 to June 15, 2005. In both years, surveys were conducted along six tributaries (Flea Valley Creek, Cedar Creek, and four unnamed tributaries designated as 1a, 9ae, 5a, and 6c) to the NFFR and their associated breeding sites on the mainstem river (Figures 1 and 2). In 2004, because of conflicts associated with the award of the contract and transmitter procurement, visual encounter surveys were used exclusively to record frog movements; whereas in 2005, surveys were conducted using visual methods and radio telemetry.

In 2004, surveys were conducted at irregular intervals for the first two weeks and continuously from April 28 to June 11, 2004. In 2005, surveys were conducted during weekdays from February 15 to April 1 and daily, including weekends from April 2 to June 15. The survey schedule was designed to alternate between a survey of Tributaries

5a and 6c on one day, followed by a survey of Cedar Creek, Flea Valley Creek, and Tributaries 9ae and 1a on the following day. In addition to surveying each tributary, river breeding sites associated with each tributary were surveyed (Figures 1 and 2). On this schedule, all tributaries and breeding sites were visited every other day during the peak breeding period, except when inaccessible due to high flows and/or dangerous conditions.

During each survey, two biologists worked as a team searching for adult frogs and recording data. All adult frogs were pursued and captured by hand, if possible. Subadult and juvenile frogs were not pursued. For each frog captured, the following data were recorded: sex (male or female); age class (subadult < 40 millimeters [mm] snout-urostyle length (SUL), or adult ≥ 40 mm SUL); weight, distance from the tributary confluence with the mainstem; location (instream, underwater, on bank, or off channel); condition (gravid, spent (= egg laid), or healthy); and activity (sitting in shade, basking, hiding, calling, swimming, foraging, amplexus, floating, or underwater).

For each captured frog, a photograph of the chin and left flank was taken using a digital camera. Photographs of frog chins (and flanks, if necessary) were used to identify individual frogs by matching their unique mottling patterns (Figure 3). Comparisons of frog chin photographs were attempted upon catching each frog by comparing its photograph to a chart of previous frog chin photographs from the same tributary. If no match was confirmed, the frog was given a unique identification number and released after all other data were collected. Because matching frog chin photographs was often not possible in the field, all photographs were reviewed at the completion of each field season to match up frogs that were given multiple identification numbers. Frog photographs were also compared between years and between tributaries within each reach to assess if frogs moved to alternate tributaries during the breeding season.

Figure 1. Cresta Reach tributary and breeding sites

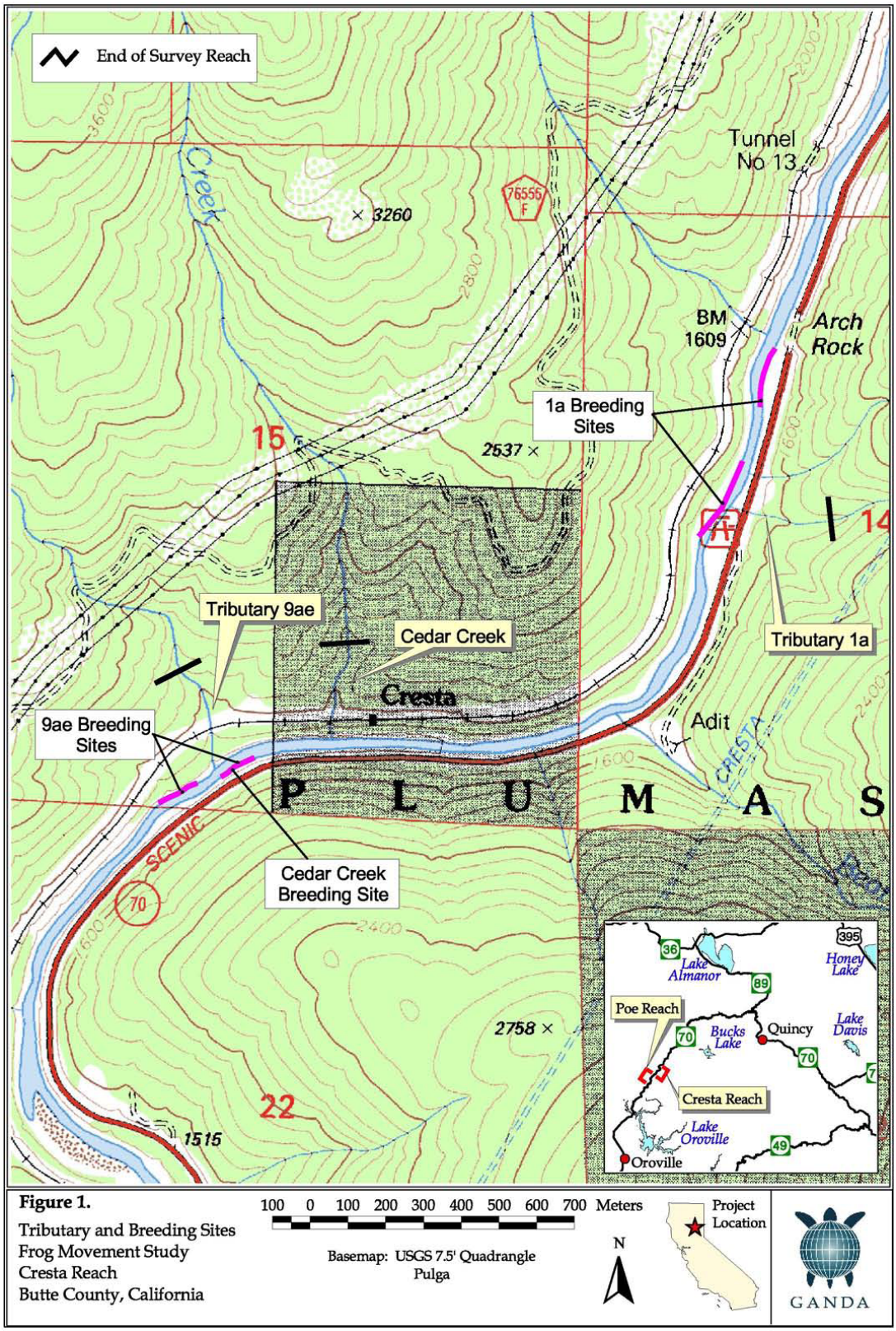
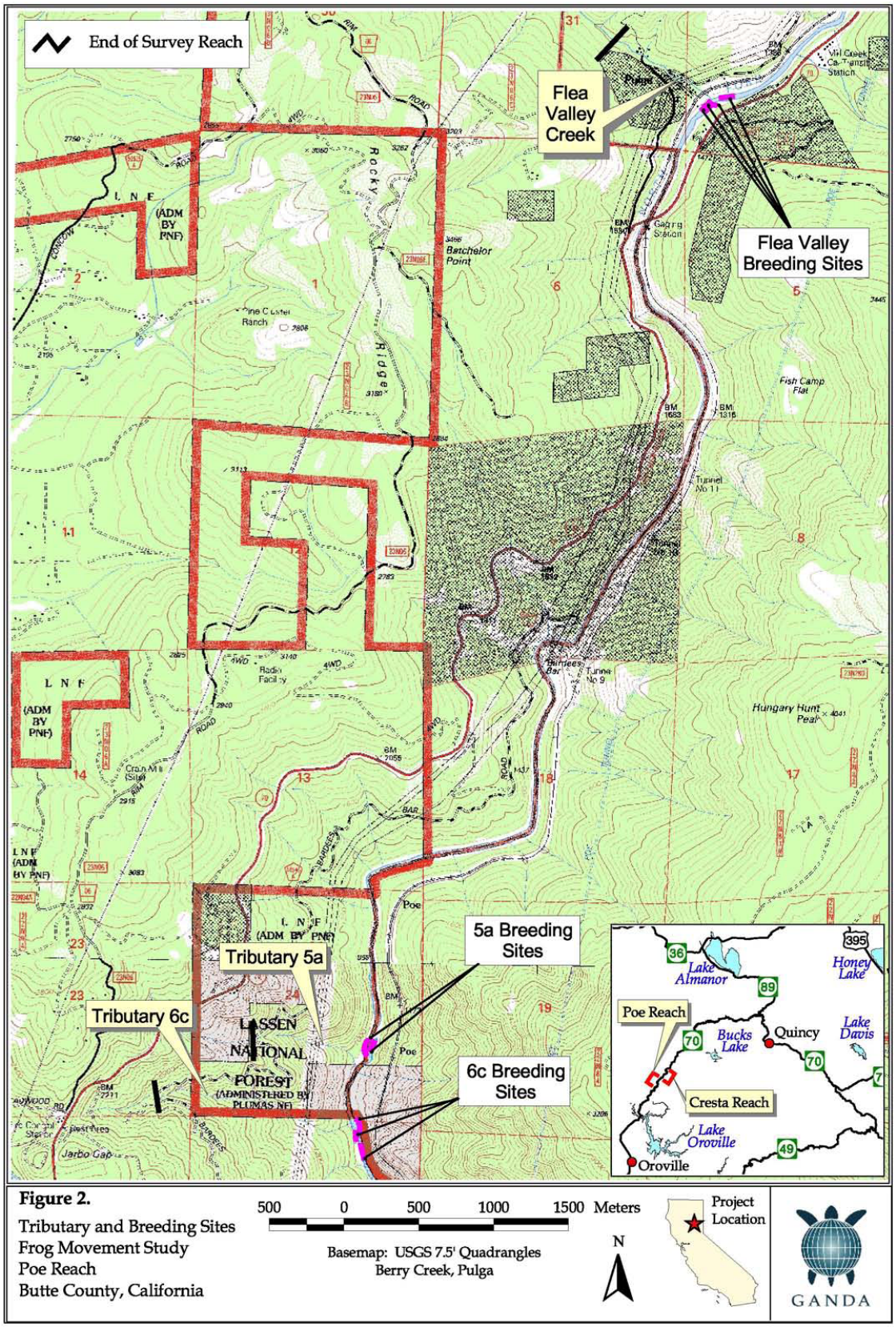


Figure 2. Poe Reach tributary and breeding sites



2.2.2. Radio Telemetry

In 2005, Holohil BD-2 radio transmitters were attached to six male and 46 female frogs. The decision to limit tagging to just 6 male frogs was based on their relatively small size (and associated problems with radio transmitter weight and battery life) and their relatively low numbers compared to female frogs on the Poe Reach (156 males versus 262 females) and absolutely low numbers on the Cresta Reach (11 males in 2 years). The number of tags was also determined in part by the study's budget. Transmitter weights were 0.90, 1.6, and 1.8 grams (g) with a corresponding battery life of 42, 77, and 98 days. Each transmitter antennae was clipped to approximately 5 cm in length after one was discovered caught in vegetation, causing premature detachment. Transmitters were attached as a waist belt made from 0.5 mm jewelry cord (Stretch Magic®) and size 14 Japanese glass seed beads (Muths 2003). The fit was adjusted by adding or removing beads to the cord. The goal was to have the belt touching the ventral side of the waist and be able to lift the transmitter of the dorsal side approximately 3–4 mm before the belt creased the skin in the abdominal region. Although transmitters were installed on the dorsal side of all frogs, they often rotated to the ventral side of the frog, a factor that may have contributed to detachments or abrasions. The total weight of the transmitter and harness did not exceed 5% of the frog's total weight. For gravid females, their weight was considered to be 13 g less, based on the observed mean weight loss of gravid females in 2004. This extra margin ensured that transmitters would not exceed 5% of the frog's weight after females laid eggs.

Radio tagging of male frogs was initiated on the Poe Reach tributaries on February 14, 2005, in an effort to document when they initiated movement to the mainstem river. Due to the relatively small size of male frogs and corresponding short battery life of the 0.90 g transmitters (42 days), those radios were planned to be replaced prior to the date the battery life was reported to expire. For female frogs, tagging was initiated on March 15, 2005, and continued until five females on each tributary were tagged. Initially, the larger 1.8 g transmitters were deployed because the battery life was over three months (98 days) long and provided a high likelihood of extending through the breeding season that was estimated to be completed by June 15. The intermediate-sized radios (1.6 g) were planned for deployment after April 1 to provide a high likelihood that their battery life (76 days) would extend through the breeding season.

Radio-tagged frogs were located during each survey concurrent with visual surveys for adult frogs. During the initial relocations, these tagged frogs were captured to inspect the waist belt and check for any signs of abrasion. During subsequent surveys, tagged frogs were located visually to record their location but were only periodically recaptured. Transmitters that were found detached or those that were removed prior to breeding were placed on alternate individuals as soon as possible. All transmitters were removed if the frog appeared injured or when breeding was documented for that individual. Of the 46 radio-tagged females, 17 transmitters (36%) were found detached and 32 frogs (70%) were injured from the belts. These detachment rates (36%) were less than those described in a study of wood frogs (*Rana sylvatica*; 45%, Muths 2003) but

similar to rates reported by a study of Oregon spotted frogs (*Rana pretiosa*; 35%, Watson et al. 2000). Rates of injuries observed during this study (70%) were much greater than those reported for wood frogs (9%, Muths 2003) and for Oregon spotted frogs (5%, Watson et al. 2000); however, the injury rate calculated for this study considered even minor abrasions as injuries, unlike the other studies. Belt injuries on females included 19 individuals with minor abrasions described as "belt marks" and 13 were cut by the belts. Of the 13 females with cuts, seven were subsequently recaptured and noted as partially or wholly healed. Of the six males that were radio-tagged, three were found with the belts detached and two with belt marks. Four males and 14 females were apparently uninjured by the belts.

2.3. Environmental Data

Concurrent with frog surveys, data was collected on local and regional environmental variables, including tributary and mainstem water temperature, air temperature, precipitation, and water flow level (mainstem and tributary). Environmental data were collected from a variety of sources. Tributary temperature was recorded on temperature data loggers that were installed in each tributary. Tributary flow levels were monitored with a staff gage. Mainstem flow levels were recorded by Pacific Gas and Electric (PG&E) gaging stations located in each reach (NF 23 in the Poe Reach and NF 56 in the Cresta Reach). Mainstem water temperatures were recorded with a PG&E temperature data logger on the Poe Reach and at the PG&E gaging station (NF 56) on the Cresta Reach. Regional air temperature and precipitation records were collected at the Jarbo Gap weather station located near the headwaters of Tributary 6c.

2.4. Data Analysis

2.4.1. Individual Frog Identification

Black and white images of frog chins and flanks were reviewed and compared to identify individuals and match up any frogs that were assigned more than one identification number. There was considerable variation in the contrast in markings between captures of the same individual but the pattern was always identical and unmistakable if the image was clear and focused correctly (Figure 3 and Appendix B, pages 10 and 11). All individuals were compared by sex within each tributary first, and then between tributaries within each reach (e.g., males on Tributary 5a were compared to males on Tributary 6c). After all frog photographs were reviewed and matched, the data were sorted to eliminate multiple identification numbers for identical frogs. For all frogs, the mean SUL, weight, number of days spent on the river, and the rate of movement (meters per day) was calculated. Movement rates were calculated by dividing the distance between two captures by the number of days between captures (e.g., Capture 1 is at 100 m and Capture 2 is at 50 m, two days later. Therefore, 100-50= 50 m moved / 2 days = 25 m/day.) The sex ratio of frogs for each tributary and reach was also calculated. The activity and location of all frogs when captured was summarized separately for radio-tagged frogs and frogs observed during visual surveys.

2.4.2. Determination of Frog Movement and Breeding Activity

The movement and breeding activity for each individual frog was categorized based on a comparison to previous observations within the same year. Frogs that were observed only one time could not be categorized as moving because there were no other observations to compare. Potential categories were: not moving, moving to the river, and breeding. Frogs were assumed to be not moving if they were relocated within 25 m of their previous position, and for female frogs, there was no change in breeding status (gravid versus spent). The 25 m distance was a somewhat arbitrary distance chosen near the outset of the study and was based on previous observations that suggested that these frogs had small home ranges on the tributaries—perhaps as small as a single plunge pool and surrounding banks out to approximately 1 m from the water's edge. Frogs were classified as moving to the river to breed once they moved > 25 m from their previous location, even if subsequent daily movements were ≤ 25 m/day.

To determine the breeding period, two criteria were developed: (1) when females changed from gravid to spent, and (2) when egg masses were laid. To determine when females changed from gravid to spent, the degree of swelling in their abdominal region and the relative tightness of the skin was evaluated. Spent females were identified by loose folds of skin on the belly and flanks. Some frogs were found in amplexus, and other spent females were located adjacent to recently laid egg masses. To determine when egg masses were laid, the stage of development of each egg mass was recorded following Gosner's (1960) table of anuran development. Based on previous work evaluating rates of development (GANDA 2003b), and data from Zweifel (1955), it was assumed that egg masses develop at a rate of four Gosner stages per day for the first two days after fertilization and two stages per day for days 3 to 10. For example, an egg mass observed on May 30 at Gosner stage 10 was assumed to have been deposited four days prior, on May 27. Egg masses that were developed beyond Gosner stage 10 were not used to estimate breeding dates because of unacceptable variability in development rates in these advanced developmental stages.

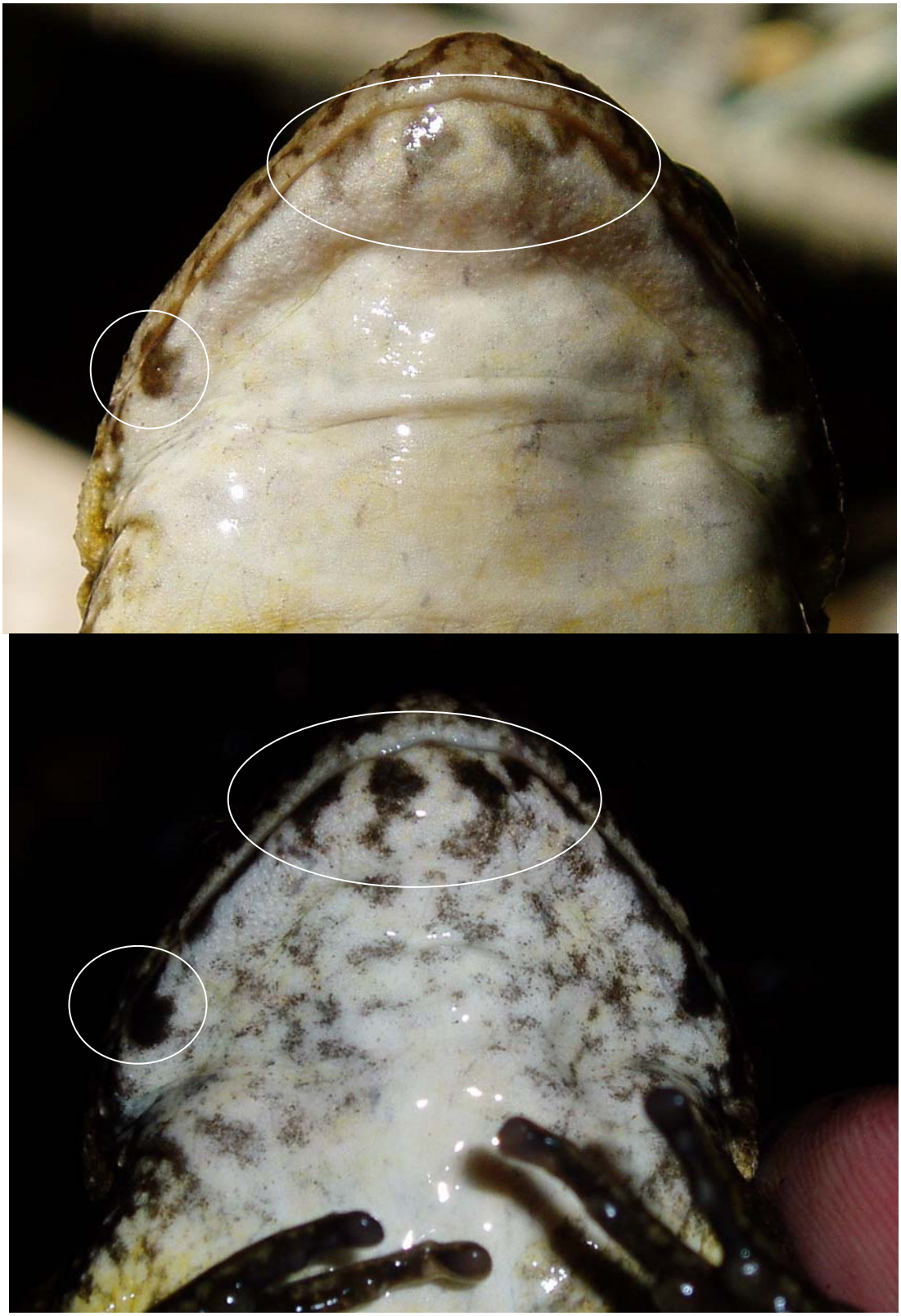


Figure 3. Adult female foothill yellow-legged frog captured on April 28, 2004, (top photograph) and the same frog recaptured on March 22, 2005

2.4.3. Statistical Analysis

Initial Movements

A series of t-tests were performed to evaluate the relationship between initial movements and environmental variables. Initially, two sample t-tests were performed on various subsets of the data to test for differences between years. This was tested only for females because adequate data was lacking for males to test between years. A significance level of $P \leq 0.1$ was chosen for these tests but it was adjusted to 0.0125 (0.10/8) to account for eight different hypotheses being tested.

Specifically, the following null hypotheses were tested separately for Poe and Cresta reach females (the reaches were tested separately because previous observations (GANDA 2003a; GANDA 2003b) documented that breeding occurs earlier on the Poe Reach compared to the Cresta Reach).

- There is no difference in the mean day of the year when frogs initiate movement between 2004 and 2005.
- There is no difference in the mean tributary water temperature when frogs initiate movement between 2004 and 2005.
- There is no difference in the mean daily air temperatures when frogs initiate movement between 2004 and 2005.
- There is no difference in the mean 10-day accumulated precipitation when frogs initiate movement between 2004 and 2005 (a 10-day window was selected for this analysis to increase the probability that some measurable precipitation data would be included).

The second analysis was directed at determining differences between the environmental conditions present when frogs initiated movements and the environmental conditions present on the fifth day prior to movement. The research team chose to contrast environmental conditions on the day frogs initiated movements with conditions on the fifth day prior to movement, to investigate if environmental conditions were associated with initial movements. The team assumed that if environmental conditions were not different between these dates, then they were not related to the movements, nor were movements triggered by environmental conditions. Paired t-tests were used, pairing the conditions present on the date frogs initiated movements with environmental conditions five days earlier. This was tested separately for Poe males, Poe females, and Cresta females. This test was not performed for Cresta males due to inadequate data. Because nine different hypotheses were tested, the significance level was adjusted to $P \leq 0.011$ (0.10/9). The null hypotheses for these analyses were as follows:

- There is no difference between the mean tributary water temperature when frogs initiate movement and the mean tributary temperature on the fifth day prior to initiating movement.

- There is no difference between the mean daily air temperatures when frogs initiate movement and the mean daily air temperature on the fifth day prior to initiating movement.
- There is no difference between the five-day accumulated precipitation when frogs initiate movement and the five-day accumulated precipitation on the fifth day prior to initiating movement (a five-day window for precipitation was selected for this analysis because a 10-day window would include five days that overlap, thereby altering the total but not affecting the net difference).

Breeding

The same approach was used to examine the relationship between breeding date and environmental variables, except precipitation was excluded because it was strongly associated with mainstem flow level. First, differences between years were tested. Specifically the following null hypotheses were tested:

- There is no difference between the mean day of the year when frogs breed in 2004 and 2005.
- There is no difference in between the mean mainstem water temperature when frogs breed in 2004 and 2005.
- There is no difference between the mean mainstem flow when frogs breed in 2004 and 2005.

The second analysis tested for differences between environmental conditions present when frogs bred and environmental conditions present on the fifth day prior to breeding. The conditions five days prior were chosen for comparison because female frogs spent a mean of 4.2 days on the river prior to breeding. Paired t-tests were used for this analysis, pairing the conditions present on the day of breeding with environmental conditions five days earlier. Because these were tested separately for the Poe and Cresta reaches, the significance level was adjusted to $P \leq 0.025$ (0.10/4). The null hypotheses for these analyses were as follows:

- There is no difference between the mean mainstem water temperature when frogs breed and the mean daily mainstem water temperature on the fifth day prior to breeding.
- There is no difference between the mean mainstem flow when frogs breed and the mean mainstem flow on the fifth day prior to breeding.

Logistic Regression

The final analytical approach was to use logistic regression analysis. Logistic regression was chosen because it can specify a probability related to a regression function of explanatory variables, particularly in situations where the interest is in the relative contribution of one or more predictor variables in determining a particular response (Scheiner and Gurevitch 2001). Using SAS statistical software (version 9), binary logistic regression was performed to examine the relationship between regional and local environmental variables and whether or not the frog was breeding. The repeated

measures option for logistic regression was used to avoid violating the assumption of independence.

The response variable ”frog breeding” was coded with a 1 if the frog was breeding and a 0 if the frog was not breeding [i.e., either not moving (nm) or moving to the river (m)]. The explanatory variables tested for inclusion in this logistic regression model were (1) day of year (a surrogate for day length), (2) five-day (MEAN, MIN, OR SLOPE) mainstem flow, and (3) five-day (MEAN, MIN, OR SLOPE) mainstem water temperature. The five-day MEAN predictor was the mean of the five daily means. The five-day MIN predictor was the minimum of the five daily minimums. The five-day SLOPE predictor was the slope of the best fit line to the five daily means. The estimated breeding date was used as the ”breeding” observation date and the ”not breeding” observation was chosen as the day five days prior to the estimated breeding date. Explanatory variables were evaluated using the scaled Pearson chi-squared criterion and only variables that were useful in predicting ”frog breeding” were retained in the model. This logistic regression was applied separately to the Cresta Female (2004 and 2005 combined) and Poe Female breeding data (2004 and 2005 combined). Although, the analysis was performed on breeding dates associated with female frogs, the results apply to the entire population (males included).

3.0 Results

In addition to addressing the main questions posed in this study, data collected on the overall frog population were analyzed to provide baseline information about the population. The following section summarizes general characteristics of the foothill yellow-legged frog population on the Poe and Cresta reaches of the NFFR. Subsequent sections of this chapter address the primary and secondary questions posed by this research.

3.1. General Characteristics of Foothill Yellow-legged Frogs on the Poe and Cresta Reaches

3.1.1. Number of Frogs

A total of 476 individual adult frogs were identified during the two-year study. This included 227 frogs in 2004 and 296 in 2005. Forty-seven frogs were captured in both years. The number of individual frogs captured per tributary ranged from five on Cedar Creek to 198 on Tributary 6c. The between-year recapture rates for each tributary ranged from 12.8% to 33.3% (Table 1).

Table 1. Summary of recapture data for the Cresta and Poe reaches of the North Fork Feather River during 2004 and 2005

Reach/Tributary		FEMALES			MALES			TOTAL		
		Total	Captured Both Years	% of 2004 Frogs Captured in 2005	Total	Captured Both Years	% of 2004 Frogs Captured in 2005	Total Individuals 2004-2005	Total Frogs Captured Both Years	% of 2004 Frogs Captured in 2005
Cresta Reach	Trib 1a	20	4	25	6	3	60	26	7	33.3
	Cedar Creek	5	1	20	0	0	0.0	5	1	20.0
	9ae	22	2	15.4	5	0	0.0	27	2	14.3
	Subtotal	**47**	**7**	**20.6**	**11**	**3**	**50**	**58**	**10**	**25**
Poe Reach	Flea Valley	87	10	22.2	52	1	4.8	139	11	16.7
	Trib 5a	45	3	12.5	36	2	13.3	81	5	12.8
	Trib 6c	130	18	32.1	68	3	11.5	198	21	25.6
	Subtotal	**262**	**31**	**24.8**	**156**	**6**	**9.7**	**418**	**37**	**19.8**
	Totals	**309**	**38**	**23.9**	**167**	**9**	**13.2**	**476**	**47**	**20.7**

In 2005, 46 female and 6 male frogs were radio-tagged (Table 2). More females were tagged than planned because their transmitters were often found detached (17 out of 46). On the Cresta Reach, only female frogs were tagged to avoid impacting the low numbers of male frogs observed during 2004. On the Cresta Reach, the sample of 13 radio-tagged females represented 65% of the females observed during 2005. On the Poe Reach, the sample of radio-tagged frogs was 19.6% of the females observed and 6% of the males observed during 2005.

Table 2. Summary of radio-tagged frogs for the Cresta and Poe reaches of the North Fork Feather River during 2005

Reach/Tributary		Females			Males		
		Total	No. radio-tagged	% radio-tagged	Total	No. radio-tagged	% radio-tagged
Cresta	Trib 1a	8	6	75.0	4	-	-
	Cedar Creek	1	1	100.0	0	-	-
	9ae	11	6	54.5	4	-	-
	Subtotal	**20**	**13**	**65.0**	**8**	**0**	**0.0**
Poe	Flea Valley	52	13	25.0	32	2	6.3
	Trib 5a	24	9	37.5	23	2	8.7
	Trib 6c	92	11	12.0	45	2	4.4
	Subtotal	**168**	**33**	**19.6**	**100**	**6**	**6.0**
Total		**188**	**46**	**24.5**	**108**	**6**	**5.6**

3.1.2. Sizes of Frogs

Female frogs were more than two times heavier than male frogs on average (Table 3). The mean weight of adult male frogs was 15.8 g and the mean snout-urostyle length was 47 mm. The mean weight of gravid adult female frogs was 37.6 g and the mean snout-urostyle length was 61 mm. The mean weight of spent adult female frogs was 31 g and the mean snout-urostyle length was 63.2 mm. Females that were weighed both gravid and spent yielded an average weight loss of 13 g (N=52, SD=4.82, range 2.5 g–25.5 g).

Table 3. Mean weight and snout-to-urostyle length (and range) of adult male and female frogs

	Males		Gravid Females		Spent Females	
Year	**Weight (g)**	**SUL (mm)**	**Weight (g)**	**SUL (mm)**	**Weight (g)**	**SUL (mm)**
2004	16.7 (8–24)	45.5 (37–56)	47.4 (18–74)	63.1 (40–81)	35.4 (19.5–53)	65.9 (50–72)
2005	15.7 (5–24.5)	48 (36–59)	34.4 (10–83)	59.6 (40–76)	29.4 (13–49.5)	59.8 (49–71)
Both Years	15.8 (5–24.5)	47 (36–59)	37.6 (10–83)	61 (40–81)	31.0 (13–53)	63.2 (49–72)

3.1.3. Location and Activity of Frogs

Non-telemetered frogs were most frequently observed instream (53%) or on the bank (38%) and occasionally underwater (9%) during surveys (Figure 4). For frogs located on the bank this included frogs that were under leaf litter (N=2) or in cracks in rocks (N=10), as well as frogs basking in the open. The furthest distance a frog was observed from the stream channel was 21 m. The activity recorded during most frog observations was basking (61%). This result is not surprising since frogs were most readily observed when they were basking. Other categories of frog activities observed included underwater, hiding, sitting in shade, swimming, floating, calling, and amplexus (Figure 4). Appendix B provides representative photographs of frog locations and activities observed during surveys.

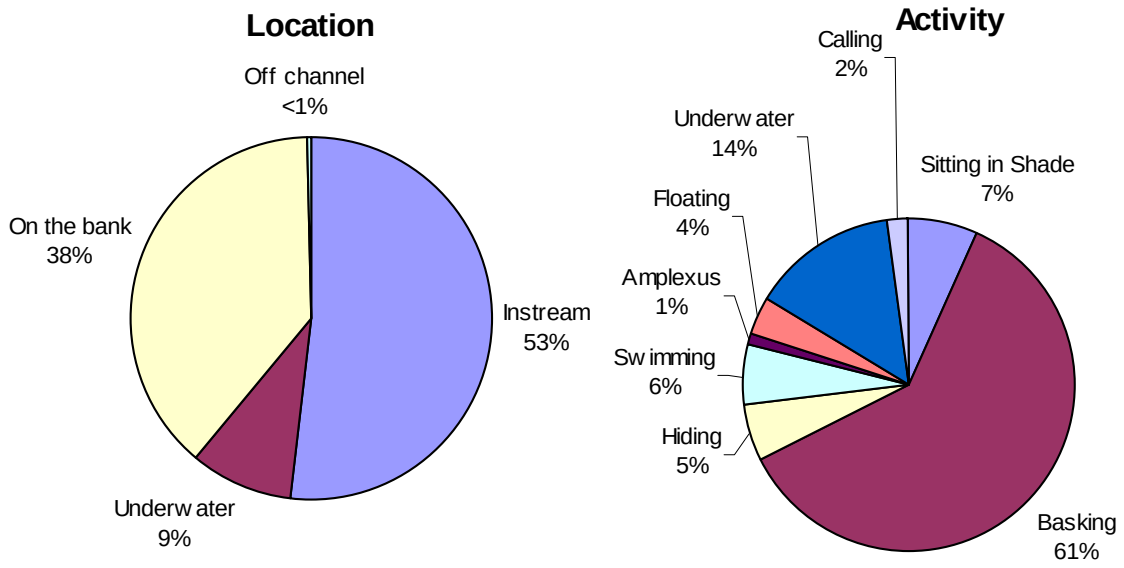


Figure 4. Location (N=678) and activity (N=735) categories for frog observations during 2004 and 2005, excluding radio-tagged frogs

The location of frogs observed during visual surveys was similar to those observed for radio-tagged frogs (Figure 5), but activity categories were considerably different between radio-tagged frogs and frogs observed during visual surveys. Basking was again the dominant activity but was reduced to 37% of observations compared to 61% for frogs observed during visual surveys.

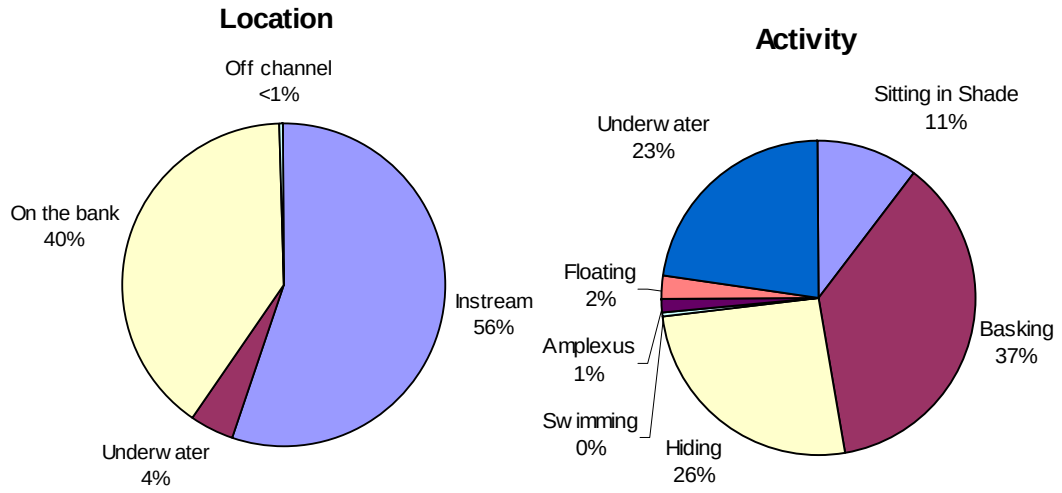


Figure 5. Location (N =535) and activity (N =485) categories for radio-tagged frogs observed during 2005

Observations of frogs hiding increased substantially from 5% for frogs found visually to 26% for radio-tagged frogs, an obvious result since telemetry enabled relocation of frogs on nearly every survey. Similarly, more frogs were observed underwater through radio-tagging (23% of observations) than from visual surveys (14%).

3.1.4. Frog Breeding Loci

All breeding was on the mainstem, except for four egg masses that were laid on tributaries. One egg mass was laid on Tributary 9ae in 2004 but was only 12 m from the mainstem. In 2005, three egg masses were laid in on Tributary 6c, all in the same pool 17 m from the mainstem.

3.1.5. Staging at Breeding Sites

There was considerable variation in the number of days male and female frogs were observed at the river (Table 4). Male frogs were present at river breeding sites for 1 to 92 days (n = 59; mean = 6.3) and females were present for 1 to 37 days (n = 56; mean = 4.2), although the single days may have reflected only one observation of that frog, especially for male frogs, who arrived earlier and stayed longer than female frogs. If observations of males that were observed only one time on the river are excluded from this analysis, then the mean minimum days on the river for males is 18.1 days for non-tagged frogs and 25.5 days for radio-tagged males (Table 5).

Two other factors were observed that are believed to have contributed to the length of time female frogs were present on the river: (1) water flow levels, and (2) sex ratio or number of male frogs. High water flow levels for an 18-day period from May 9–27, 2005, apparently delayed at least six females on the Poe Reach from breeding, and similar observations were made on the Cresta Reach. During this period, mean daily flows ranged from ~475 to 15,361 cfs. It is speculated that this period of high flow explains the two-day increase in time spent on the river for females between 2004 (3.1 days) and 2005 (5.1 days). Differences in sex ratios or lack of male frogs at breeding sites apparently also influenced the number of days spent on the river. On the Cresta Reach, where the sex ratio was somewhat more female-skewed than the Poe Reach (Table 4), and there were only 11 males observed during the entire study (Table 1), females spent about twice as many days on the river as Poe Reach females did (6.1 versus 3.3 days).

Table 4. Minimum number of days that frogs were present at mainstem breeding sites and sex ratio for each tributary and reach during 2004 and 2005. Data are divided according to tributary of origin, reach, and combined reaches.

Reach/Tributary		Mean (range) Minimum Number of Days at Mainstem Breeding Sites						Sex Ratio (Female to Male)	
		2004		2005		Both years males	Both years females	2004	2005
		males	females	males	females				
Cresta	1a	10.0 (1–26)	1.1 (1–2)	13.3 (1-50)	9.2 (1–17)	11.4	1.1	3.2:1	2.0:1
	Cedar Creek	-	6.0 (1–12)	19.0	37.0	19.0	13.8	na	na
	9ae	-	11.0 (3–26)	46.5 (1-92)	3.7 (1–22)	46.5	5.8	13.0:1	2.8:1
	Subtotal	**10.0**	**4.5**	**23.6**	**7.6**	**17.9**	**6.1**	**5.7:1**	**2.5:1**
Poe	FVC	4.5 (1–21)	1.3 (1–3)	6.5 (1-40)	2.2 (1–18)	5.5	1.8	2.1:1	1.6:1
	5a	5.2 (1–18)	3.3 (1–9)	5.6 (1-37)	2.3 (1–6)	5.5	2.9	1.6:1	1.0:1
	6c	4.9 (1–17)	3.1 (1–15)	3.3 (1-30)	6.8 (1–34)	4.0	5.4	2.2:1	2.0:1
	Subtotal	**4.8**	**2.3**	**4.8**	**4.2**	**4.8**	**3.3**	**2.0:1**	**1.7:1**
Both reaches	**Total**	**5.4**	**3.1**	**7.1**	**5.1**	**6.3**	**4.2**	**2.3:1**	**1.7:1**

Table 5. Minimum number of days that male frogs observed greater than one time were observed at mainstem breeding sites for each tributary in 2004, 2005, and both years combined. Data are divided according to tributary of origin and reach. Standard deviation and range are provided for those cells where N > 3.

Reach/Tributary		Mean (range) Minimum Number of Days at Mainstem Breeding Sites			
		2004	2005	Both Years	Radio-tagged Males
Cresta	1a	16 (3–26) SD=11.8	50 (n=1)	24.5 (3–50) SD=19.5	
	Cedar Creek	-	19 (n=1)	19 (n=1)	
	9ae	-	92 (n=1)	92 (n=1)	
	Subtotal	**16** **SD=11.8**	**53.7** **SD=36.6**	**34.8** **SD=51.6**	
Poe	FVC	9.8 (3–21) SD=6.6	9.5 (4–15) SD=7.8	9.8 SD=6.3	33.5 (26-41, n=2) SD=10.6
	5a	13.5 (9–18) SD=5.2	19.7 (10–39) SD=16.7	17.2 SD=12.7	10 (n=1)
	6c	10.3 (3–17) SD=4.4	30 (n=1)	12.4 SD=7.8	25 (n=1)
	Subtotal	**10.5** **SD=5.3**	**18.0** **SD=13.5**	**12.5** **SD=8.7**	**25.5** **SD=12.7**
	Total	**11.4** **SD=6.6**	**29.9** **SD=27.7**	**17.3** **SD=18.3**	**25.5** **SD=12.7**

3.1.6. Movement Rates

During both years of the study, a seasonal frog movement pattern was observed. In the pre-breeding season, males and females were resident on tributary streams. Frogs were often located in the same location (e.g., same pool) on multiple surveys. As the breeding season approached (i.e., March) the researcher team observed a pattern of males initiating movements to the river while most females remained on the tributary. Females moved to the river after males and moved at more than twice the rate of males. During periods of movement, females moved at a mean minimum daily rate of 51.1 m/day (N=206, SD=51.6) and males moved 26.2 m/day (N=42, SD=24.4) per day. The longest distance traveled was 1899 m. This trip was completed in ≤ 6 days, yielding a minimum mean daily movement rate of 316.5 m, which included time for breeding on the river. Female movement rates were nearly identical each year within each reach; however, Poe Reach females moved at more than twice the rate of Cresta females in each year (Table 6). This difference was likely related to the difference in the lengths of the tributaries in each reach. Longer tributary lengths in the Poe Reach (mean = 966 m) compared to the Cresta Reach (mean = 270 m) probably led to observations of longer distance movements.

These movement rates are underestimates of the rate of movement because frogs probably departed sites later than when their last position was noted, and they arrived to the new location earlier than surveyors did. Because the interval of days between relocations was used as the denominator in these calculations, their rate of movement was underestimated. All tributaries continued above the point established as the top of the site, thus frogs may have moved farther than where they were last detected.

Table 6. Minimum mean daily rate of frog movement during 2004 and 2005

Reach/Tributary		Mean Minimum Daily Rates of Movement (m/day)			
		2004 females	2004 males	2005 females	2005 males
Cresta	Trib 1a	13.0 (7–20)		23.2 (5–57)	
	Cedar Creek	45.2 (33–58)		-	
	9ae	19.5 (7–75)		22.5 (3–61)	
	Mean	**21.3**		**22.9**	
Poe	Flea Valley	32.7 (7–87)	6.7 (2–9)	33.9 (3–170)	19.1 (8–38)
	Trib 5a	49.4 (8–114)	-	64.3 (4–240)	32.6 (8–128)
	Trib 6c	76.1 (23–273)	25.2 (9–41)	65.9 (4–317)	26.6 (6–83)
	Mean	**58.1**	**14.1**	**58.1**	**27.8**

3.2. Environmental Conditions

Most environmental conditions were similar between the two years of the study. Both years were considered normal water years and there were periods when the river was spilling over the dams. For the 35-year period from 1970 to 2005, the Poe and Cresta reaches experienced the full range of water year types, including 10 critically dry, 3 dry, 9 normal, and 14 wet years. For the same period, there were 9 years (26%), when mainstem flows were greater than 1000 cfs on June 1 (PG&E unpublished data).

In 2004, mainstem flow on the Cresta and Poe reaches peaked on February 18 with 16,499 cfs on the Cresta Reach and 19,965 cfs on the Poe Reach (Figures 6 and 7). Flows on the Poe Reach were variable from February 18 until April 14, 2004. Some of this variability was due to water releases provided between March 31 and April 6, 2004, for a separate study designed to assess the effects of flow level on foothill yellow-legged frog habitat (GANDA 2004). After April 14, 2004, mainstem flow on the Poe Reach never increased above 200 cfs (Figure 7).

In 2005, early season flow levels were near the base level from February through April except for a 12-day period in late March to early April when flows increased to the 2000 to 4000 cfs range. From April 1 through May 8, flows were near base level, but from May 9 through May 29 flows were sustained at high levels that peaked at 13,181 cfs on the Cresta Reach and 15,361 cfs on the Poe Reach on May 15, 2005.

The 2005 breeding season was cooler and wetter compared to 2004. Average monthly air temperature for April and May, respectively, were 14.2°C and 18.6°C in 2005 and 17.3°C and 20.4°C in 2004. Total monthly precipitation during April and May varied substantially between years. The total precipitation recorded during April and May 2004 was 0.51 cm and 1.66 cm, respectively; whereas, in 2005, total precipitation recorded was 2.16 cm in April and 7.7 cm in May.

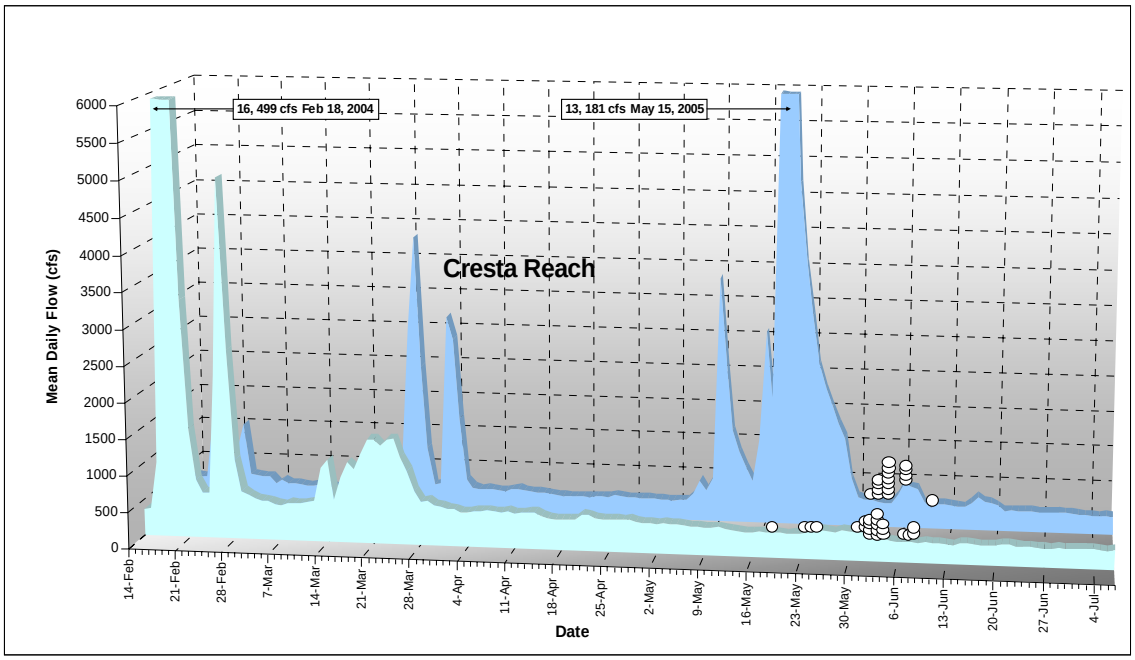


Figure 6. Cresta Reach hydrograph and breeding dates in 2004 (bottom, foreground) and 2005 (top, background). Round circles represent individual egg masses laid on those days.

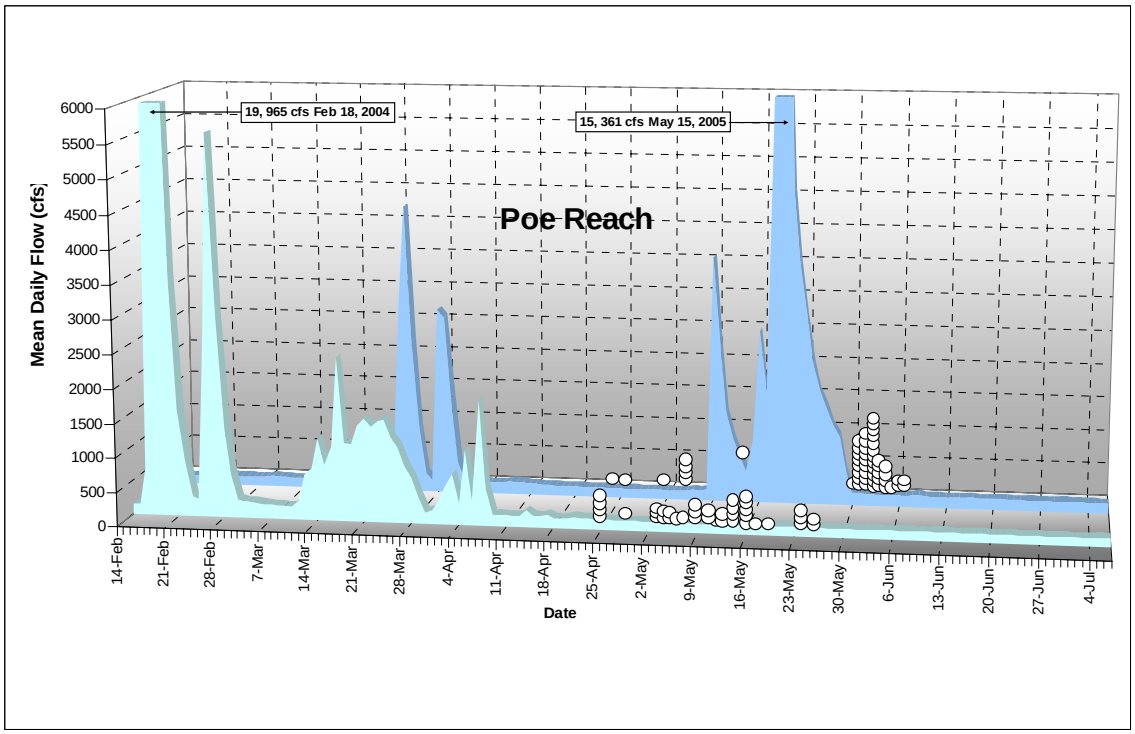


Figure 7. Poe Reach hydrograph and breeding dates in 2004 (bottom, foreground) and 2005 (top, background). Round circles represent individual egg masses laid on those days.

3.3. Initial Movements

In general, movement patterns appeared to be associated with day of the year, water temperature, and flow level. As the day of the year advances, water temperature increases and mainstem flow decreases, and frogs begin moving to the river. As an example, all of the environmental variables for Flea Valley Creek were graphed against the range of dates that frogs initiated movements (Figure 8). Because this pattern was present for all tributaries, the above-mentioned environmental variables were used for hypothesis testing.

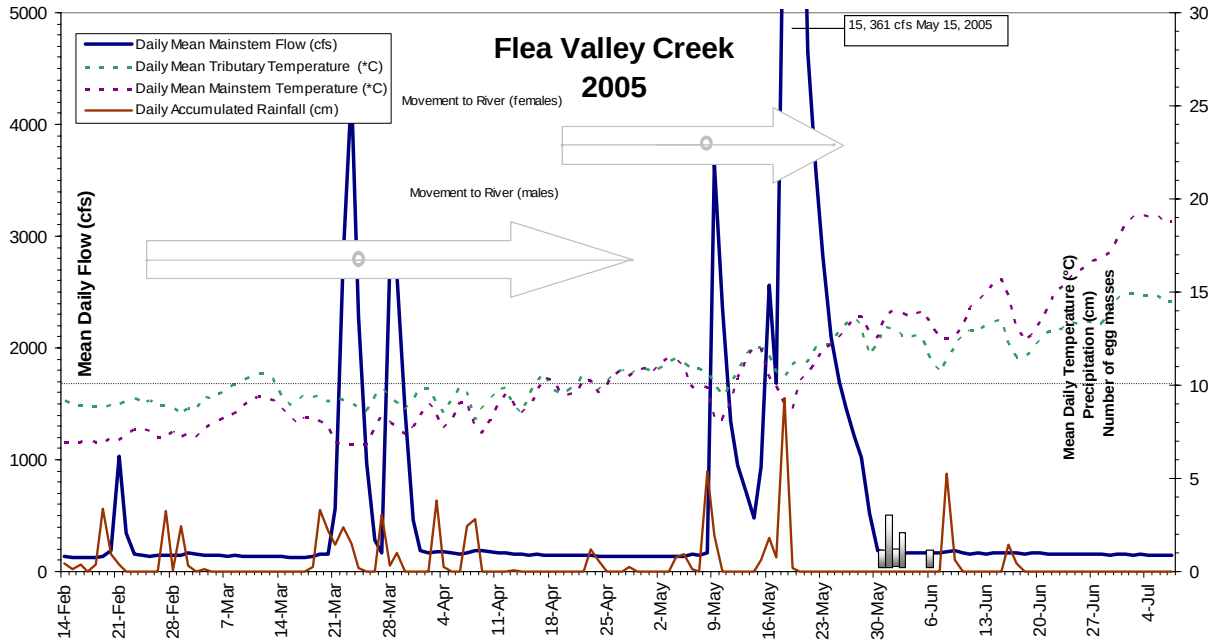


Figure 8. Environmental variables associated with initial movement and breeding dates of frogs on Flea Valley Creek in 2005. Arrows indicate the range (endpoints) and mean dates (open circles) of initial movements for male and female frogs. Stacked bars indicate the numbers of egg masses laid at the breeding sites associated with Flea Valley Creek.

In 2004, surveys were started too late in the breeding season to detect initial movements for all frogs on Poe Reach tributaries. Approximately 20 adult male and two adult female frogs were observed at Poe Reach breeding sites in late March and during the first week of April 2004 prior to initiating this study on April 7, 2004. Low numbers of males on the Cresta Reach and only one year of data on Poe Reach males precluded any statistical analysis of initial movement for male frogs. Even so, in both years, it appeared that male frogs moved to the river before female frogs. In 2005, the first male frog detected moving to the river was on February 23 on Flea Valley Creek and the first female movement to the river was on April 1 at Tributary 6c. On the Cresta Reach the first movement detected was a female on April 22, 2005 at Tributary 9ae. Table 7 summarizes the mean initial movement dates and associated environmental variables of male frogs on the Poe Reach in 2005.

Table 7. Initial movement date for Poe Reach males in 2005 and associated tributary water temperature, air temperature, and precipitation recorded. No initial movement data was obtained for Cresta males in both years, and none were obtained for Poe males in 2004.

Poe Reach Tributaries	Mean Date of Initial Movement 2005	Mean Tributary Water Temperature (°C)	Mean Daily Accumulated Precipitation (cm)	Mean Air Temperature (°C)
FVC (N=5)	3/23/2005	9.74	0.53	10.91
5a (N=7)	4/27/2005	11.46	0.13	12.93
6c (N=5)	4/16/2005	11.11	0.02	12.32
Mean (N=17)	4/14/2005	10.85	0.21	12.16

3.3.1. Between-year Comparison of Initial Movements

Cresta Reach

The mean date Cresta Reach females initiated movement from tributaries toward the mainstem NFFR was nearly the same in 2004 (May 9) and 2005 (May 5), and the difference was not statistically significant ($P = 0.34$). The mean tributary water temperature when movement was initiated was similar in both years 12.2°C in 2004 versus 11.6°C in 2005, and the difference was not significant ($P = 0.1$). Likewise, mean daily air temperature when Cresta females initiated movements was similar in both years (16.5°C in 2004 versus 15.0°C in 2005) and was not significantly different ($P = 0.263$) nor was the 10-day accumulated precipitation different between years ($P = 0.06$).

Poe Reach

The mean date Poe Reach females initiated movements was on May 4 in each year and the small difference was not significant (P = 0.923). Mean daily tributary water temperature was 13.8°C in 2004 and 12.1°C in 2005 and the difference (1.75°C degrees higher in 2004) was not statistically significant ($P = 0.047$). Mean daily air temperature when Poe Reach females initiated movements was 4.47°C warmer in 2004 but the difference was not significant ($P = 0.213$). The 10-day accumulated precipitation was greater in 2005, but the difference was not significant ($P = 0.073$). Table 8 summarizes the dates when females initiated movements, as well as the associated tributary water and air temperatures and the 10-day accumulated precipitation.

Table 8. Mean date, tributary water and regional air temperature, and 10-day accumulated precipitation recorded when female frogs initiated movements from tributaries to mainstem river breeding sites in 2004 and 2005

Reach/Tributary		Mean Date of Initial Movement		Mean Tributary Water Temperature (°C)		Mean Air Temperature (°C)		Mean 10-day accumulated precipitation (cm)	
		2004	**2005**	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**
Cresta (N=11)	1a	5/15	5/8	12.9	11.1	18.9	14.9	0.03	5.5
	Cedar	5/7	-	12.0	-	15.5	-	0	Na
	9ae	5/8	5/3	12.1	12.0	15.9	15.1	0	3.0
	Mean	**5/9**	**5/5**	**12.2**	**11.6**	**16.5**	**15.0**	**0.01**	**4.1**
Poe (N=28)	FVC	-	5/7	-	11.5	-	16.8	0	4.1
	5a	5/6	5/15	14.2	13.3	18.5	15.7	0	4.9
	6c	5/2	4/28	13.1	11.7	21.9	14.2	0	5.4
	Mean	**5/4**	**5/4**	**13.8**	**12.1**	**19.6**	**15.2**	**0**	**5.1**

3.3.2. Comparison to Conditions Five Days Prior to Initial Movements

The mean date of initial movement for females on both reaches was not different between years; nor were tributary water, air temperature, and 10-day accumulated precipitation different between years. Because failure to reject these null hypotheses does not necessarily lead to a conclusion they are true, the environmental conditions present at the time when movements were initiated were compared to conditions present five days prior to movement to investigate if water and air temperature triggered movement. A five-day window for precipitation was selected for this analysis because a 10-day window would include a five-day-long period of overlap, thereby increasing each mean by the same amount without changing the net difference. These tests all showed moderate differences and none were statistically significant (Table 9)—a finding that suggests day length (as determined by day of the year) is the trigger to initiate movements rather than environmental conditions. If environmental conditions were triggering frog movements, larger, statistically significant differences would be expected between environmental conditions when frogs moved and conditions five days prior to movement.

Table 9. Difference between tributary water and air temperature, and five-day accumulated precipitation recorded when female frogs initiated movements from tributaries to mainstem river breeding sites and conditions five days prior

Environmental Variable	Reach	
	Cresta (N=11)	**Poe (N=28)**
Mean Tributary water temperature (°C)		
Day of Initial Movement	11.817 (SD=0.649)	12.277 (SD=1.323)
5 days prior	11.528 (SD=1.147)	11.950 (SD=1.597)
Difference (P-value)	0.289 (*P*=0.548)	0.327 (*P*=0.16)
Mean Air temperature (°C)		
Day of Initial Movement	15.55 (SD=2.31)	15.63 (SD=0.649)
5 days prior	14.76 (SD=5.16)	13.531 (SD=5.012)
Difference (P-value)	0.80 (*P*=0.684)	2.10 (*P*=0.053)
Mean 5 day accumulated precipitation (mm)		
Day of Initial Movement	2.24 (SD=3.88)	2.277 (SD=3.44)
5 days prior	0.44 (SD=0.70)	2.698 (SD=3.267)
Difference (P-value)	1.80 (*P*=0.132)	0.421 (*P*=0.67)

3.4. Breeding

3.4.1. Between-year Comparison of Breeding

Cresta Reach

On the Cresta Reach, the breeding period spanned 22 days in 2004 (May 18 to June 8) and nine days in 2005 (June 1 to 10). The mean date when egg masses were laid was relatively close each year (May 31, 2004, and June 4, 2005) but the difference was statistically significant between years (P = 0.007). Mainstem flow was nearly the same each year and was not significantly different (P = 0.509). Mainstem water temperature was 1.5 degrees lower in 2005 (14.75°C in 2004 versus 13.17°C in 2005) and the difference was significant (P < 0.005) (Table 10).

Poe Reach

Breeding was documented first on the Poe Reach compared to the Cresta Reach in each year (Table 10). In 2004, egg masses were first deposited over a 32-day period between April 24 and May 25. In 2005, the breeding period was 45 days and spanned from April 23 to June 6. The mean date when egg masses were laid was 18 days later in 2005 (May 27) than in 2004 (May 9) and the difference was significant (P < 0.005). Mainstem flow and water temperature were also significantly different each year (132 cfs in 2004 versus 171 cfs in 2005; 12.3°C in 2004 versus 13.2°C in 2005).

Table 10. Mean breeding date, mainstem flow, and water temperature when frogs bred during 2004 and 2005

	Mean Breeding Date			**Mean Daily Mainstem Flow (cfs)**			**Mean Daily Mainstem Water Temperature (°C)**		
Reach	2004	2005	Difference (P-value)	2004	2005	Difference (P-value)	2004	2005	Difference (P-value)
Cresta	May31 (N=23)	June 4 (N=17)	-3.44 (*P*=0.007)	343.2 (SD=38.6)	349.5 (SD=17.5)	-6.28 (*P*=0.509)	14.75 (SD=1.11)	13.17 (SD=0.88)	1.578 (*P*<0.005)
Poe	May 9 (N=40)	May 27 (N=50)	-17.61 (*P*<0.005)	132.05 (SD=4.59)	171.4 (SD=15.5)	-34.71 (*P*=0.000)	12.30 (SD=0.80)	13.19 (SD=1.08)	-0.895 (*P*=0.000)

3.4.2. Comparison to Conditions Five Days Prior to Breeding

Cresta Reach

On the Cresta Reach, mainstem flow was 88 cfs lower and water temperature was 0.53°C higher when egg masses were laid, but neither difference was statistically significant (Table 11).

Poe Reach

Environmental conditions on the Poe Reach were significantly different from conditions present five days prior to breeding (Table 11). Mainstem flow was 506 cfs lower and water temperature was 0.503°C higher compared to conditions present five days before the mean breeding date, but only the difference in flow was significant (P<0.000).

Table 11. Difference between mainstem water temperature and flow level recorded when frogs breed and conditions five days prior

Reach	Mainstem Water temperature (°C)			Mainstem flow (cfs)		
	Breeding date	5 days prior	Difference (P-value)	Breeding date	5 days prior	Difference (P-value)
Cresta N=40	14.078 (SD=1.281)	13.549 (SD=0.915)	0.529 (*P*=0.201)	373.2 (SD=89.5)	460.9 (SD=327.5)	-87.8 (*P*=0.112)
Poe N=92	12.802 (SD=1.058)	12.298 (SD=1.385)	0.503 (*P*=0.094)	161.4 (SD=55.7)	667.8 (SD=695.1)	-506.4 (*P*=0.000)

In 2004 and 2005, the mean minimum daily mainstem water temperatures were ≥ 10°C when egg masses were deposited (Figure 9). Mainstem water temperature appears to have a strict threshold that must be met before frogs breed, whereas flow level was more variable when frogs initiated breeding. Although there were at least six frogs that bred when flows were > 100% above base flow (i.e., > 200% of base flow, or twice the base flow), all breeding was on the declining limb of the hydrograph and was clustered below flow levels that were ≤ 55% above base flow. Apparently, the absolute flow level is not as important as the location of the flow on the hydrograph. While some frogs did breed when flows were > 100% of base flow, in each case the mean daily flow was declining steeply. In those instances, apparent as outliers in Figure 9, only one of the associated egg masses was scoured due to high flows increasing on the following day but previously laid egg masses were also scoured.

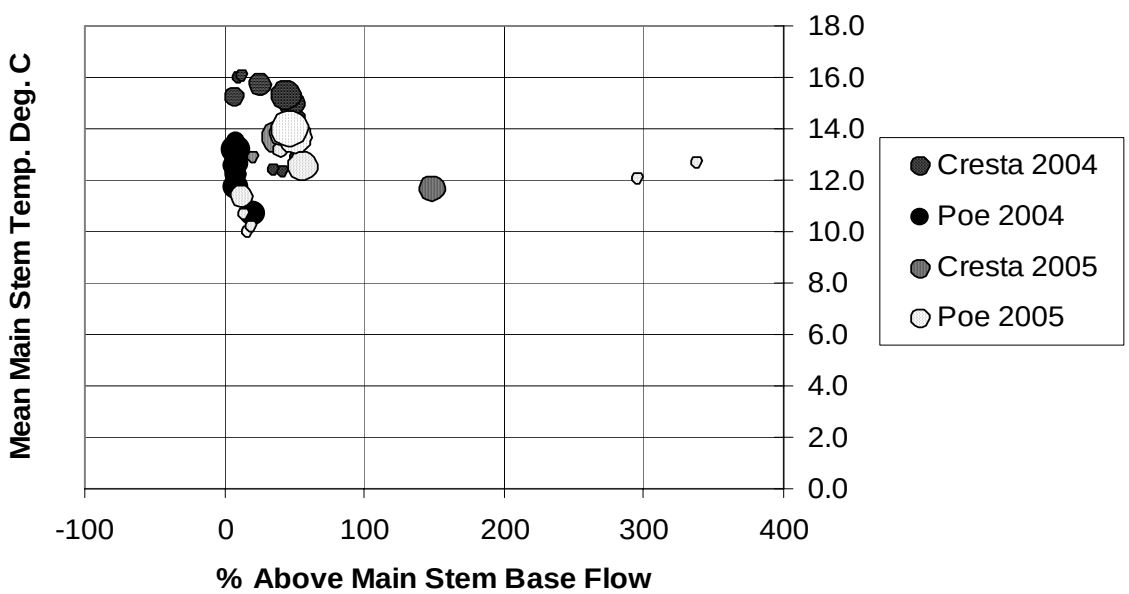


Figure 9. Mean mainstem temperatures and percent above mainstem base flow on estimated breeding dates (N=132) in the Poe and Cresta reaches during 2004 and 2005. Dot size reflects the number of occurrences. Outliers beyond 100% above base flow include 2 Poe Reach and 4 Cresta Reach breeding dates from 2005.

3.4.3. Logistic Regression

Logistic regression for the response variable "frog breeding" (1=breeding, 0=not breeding) was performed separately on the Cresta and Poe Reach data sets. Although, the data were based primarily on observations of female frogs, the results apply to the population as a whole (including males) since successful reproduction requires a male and a female. The hypothesis test results are provided in Table 12 below.

Table 12. Cresta and Poe Reach Female Logistic Regression Effect Tests

	Estimate		Standard Error		95% confidence limits				Z Pr > |Z|			
Parameter	Cresta	Poe	Cresta	Poe	Cresta		Poe		Cresta		Poe	
Intercept	1.5605	-1.0891	0.4732	0.7978	0.6330	2.4880	-2.6526	0.4745	3.30	0.0010	-1.37	0.1722
Day	-0.0142	0.0027	0.0033	0.0064	-0.0205	-0.0078	-0.0098	0.0153	-4.35	< .0001	0.42	0.6719
Mainstem Flow Slope	0.0011	0.0008	0.0003	0.0002	0.0004	0.0018	0.0003	0.0013	3.21	0.0013	3.32	0.0009
Mainstem Temperature Slope	0.2678	2.1007	0.1344	0.2712	0.0044	0.5311	1.5691	2.6323	1.99	0.0463	7.75	< .0001

The interpretations of the parameter estimates are as follows:

Cresta Reach:

- The estimated odds of "breeding" rather than "not breeding" decreases by 1% as the day of the year increases by 1.
- The estimated odds of "breeding" rather than "not breeding" increases by 0.1% as the five-day mainstem flow trend (slope) increases by 1.
- The estimated odds of "breeding" rather than "not breeding" increases by 31% as the five-day mainstem water temperature trend (slope) increases by 1.

Poe Reach:

- The estimated odds of "breeding" rather than "not breeding" increases by 0.3% as the day of the year increases by 1.
- The estimated odds of "breeding" rather than "not breeding" increases by 0.08% as the five-day mainstem flow trend (slope) increases by 1.
- The estimated odds of "breeding" rather than "not breeding" increases by 717% as the five-day mainstem water temperature trend (slope) increases by 1.

The estimated probability of breeding, given a certain set of environmental conditions, can be calculated by plugging in specific values for the environmental variables into the following formula (using Cresta female estimates).

Estimated Probability = $e^{(1.5605 - 0.0142\ (day) + 0.0011\ (flow\ slope) + 0.2678\ (temperature\ slope))} / (1 + e^{(1.5605 - 0.0142\ (day) + 0.0011\ (flow\ slope) + 0.2678\ (temperature\ slope))})$

For example, the estimated probability of breeding when the day of the year is 139 (June 1), the five-day mainstem flow slope is -20 (i.e., the daily mean mainstem flow values are declining by 20 cfs per day, on average), and the five-day mainstem water temperature slope is 0.4 (i.e., the daily mean mainstem water temperatures are increasing by 0.4°C per day, on average) equals 0.42. The calculation is as follows:

$$e^{(1.5605 - 0.0142\ (139) + 0.0011\ (-20) + 0.2678\ (0.4))} / (1 + e^{(1.5605 - 0.0142\ (139) + 0.0011\ (-20) + 0.2678\ (0.4))}) = 0.42$$

3.4.4. Alternative Breeding Cues

While conducting surveys, some evidence was observed that suggested larger female frogs moved and bred before smaller female frogs. Specifically on Tributary 6c, where there was the highest number of frogs, there was a significant trend in larger (heavier) females breeding earlier than smaller females (Figure 10). A similar correlation appeared with lengths of these frogs ($R^2 = 0.76$, N = 13 observations), indicating that older frogs may breed earlier. However, these apparent functional relationships were not observed on other tributaries, or for the population as a whole ($R^2 = 0.11$ and 0.13 for weight and length, respectively).

The research team also explored the influence of female weight-to-length ratio on timing of breeding, and speculated that females in better condition (i.e., a higher weight-to-length ratio) would breed earlier. The length to weight regression was calculated for the entire population of gravid females (length (mm) = 1.7937 x weight (g) - 69.153; $R^2 = 0.83$) and plotted against the date of oviposition. There was no relationship between frog condition and date of breeding (R^2=0.10 for all frogs, and R^2=0.06 for Tributary 6c frogs).

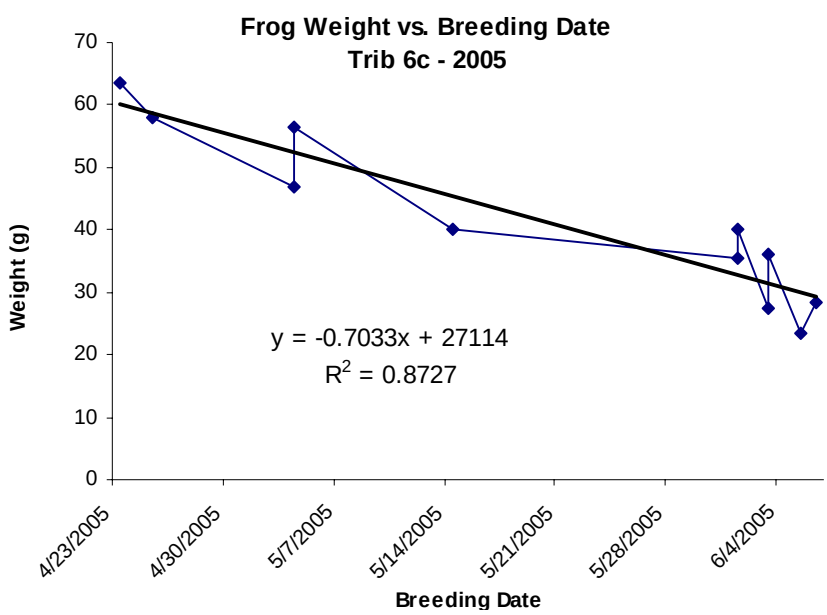


Figure 10. Breeding dates of female frogs of known weight from Tributary 6c on the Poe Reach in 2005

3.5. Intertributary Movements

Most males and females were observed breeding at the site nearest to the confluence of their tributary with the mainstem. However, in 2005 three observations of male frogs and one unconfirmed observation of a female frog were made that documented movement to an alternate breeding site. Three male frogs on the Poe Reach moved to alternate breeding sites associated with tributaries different from where they were initially found. A male from Tributary 5a moved approximately 0.5 kilometers (km) downstream to the Tributary 6c breeding area and a male from Tributary 6c moved upstream to the 5a breeding area. The third male moved upstream from Flea Valley Creek to the breeding areas associated with Mill Creek, approximately 0.8 km upstream on the NFFR.

Only one female was observed to apparently move to an alternate breeding site. The signal of a radio-tagged female from Tributary 9ae was detected approximately 800 m downstream from the confluence of her tributary with the NFFR. This change in location occurred over a one-day period concurrent with rapidly increasing flow levels which may have washed this frog or her transmitter downstream. Although it is possible that the transmitter and/or frog was washed downstream, this is unlikely in part because the transmitter was ultimately located detached from the frog under a boulder near an alternate breeding site approximately 300 m above the frogs initial relocation and 0.5 km below the confluence of Tributary 9ae with the NFFR. It is speculated that the downstream movement may have been accidental (i.e., she was washed downstream during high flows), however, it may have been related to low numbers or absence of males at the breeding site nearest her tributary where very few males were observed each year.

3.6. Culverts

In general, most culverts on study tributaries appeared compatible with frog movements from tributaries to the mainstem river. Only three observations of frogs inside culverts were made, and frogs were never observed crossing over the tops of culverts. Many frogs were observed just above or below culverts, suggesting they were about to pass through a culvert or had recently passed through the culvert. On Flea Valley Creek, a large (~4 m x 4 m x 10 m) concrete culvert under the railroad was negotiated easily by the few frogs observed at that location. Indeed, this culvert was easily negotiated by surveyors as well. At Tributary 1a, one observation of a subadult was made inside of a smaller, ~1.5 m diameter corrugated metal culvert passing under Highway 70. Several observations of adult frogs immediately upstream and downstream of this culvert were also documented. It is likely that this culvert at Tributary 1a was easily negotiated by frogs and that the areas immediately upstream and downstream of this culvert were excellent basking sites due to the lack of vegetative overstory.

Only one tributary culvert (Cedar Creek) was considered problematic for frog passage, and coincidentally the number of individual frogs observed (N = 5) on this tributary during the entire study was extremely low. The culvert passing under the railroad at

Cedar Creek was placed at an angle similar to the high gradient natural slope. Immediately upstream of the culvert was the base of an approximately 25 m high waterfall. It is suspected that if frogs traveled through this culvert they might risk being swept into the fast-moving water and injured. The outlet of this culvert was suspended approximately 2 m above the tributary at its downstream end where it fed into a 79 m high waterfall that descends directly to the mainstem river. Frogs may have been able to negotiate this culvert heading downstream but they likely had greater difficulty on their return upstream. An alternative to movement through this culvert on Cedar Creek is the overland route, passing across the railroads tracks. Frogs on tributaries 5a and 6c were observed in dry sections of those creeks on several occasions, and it is assumed that all moving frogs on those tributaries passed through these dry stretches. This suggests that frogs are capable of overland routes but prefer to stay within creek channels during movements.

One radio-tagged female frog was relocated at the Tributary 1a culvert that passes under Highway 70 during repeated surveys. The signal emanated from a hole in the top of concrete material surrounding the culvert. When the frog failed to move, the hole was carefully enlarged in a successful attempt to locate the frog which was found dead. Although this frog may have died of natural causes unrelated to the culvert, careful inspection of the site where the frog was located suggested the hole was completely overhung, which probably trapped the frog and led to its death.

4.0 Conclusions and Recommendations

4.1. Conclusions

The mean date female frogs initiated movement to the river was nearly the same in both years of the study despite some differences in the measured environmental variables (i.e., air temperature, water temperature, and flow level). This finding suggests that female frogs are responding to day length or photoperiod rather than to environmental triggers to initiate movement. Additional evidence that day length triggers frog movements is that environmental conditions were not different between the day that females initiated movements and the day five days prior to initiating movement. If frogs were waiting for an environmental trigger to initiate movement, a significant difference in environmental conditions would be expected. While the absence of evidence showing a response to environmental variables on the tributaries points to day length as the trigger, it is possible that time of year could be linked with a temperature threshold on the tributary, since there is no other way for the frogs to know mainstem river conditions while residing in refugia. Mean daily temperatures of tributaries were all above 10°C when movements were initiated, except one (9.7°C).

The mean breeding date was similar between years on the Cresta Reach (3.4 days later in 2005) but was substantially different on the Poe Reach (17.6 days later in 2005). From variation seen in earlier work on the NFFR (GANDA 2003a; GANDA 2003b; GANDA 2005), it is suspected that data from additional years of study and a larger sample size would refine the understanding of the factors affecting mean breeding date between years. This analysis provides mixed results on environmental conditions associated with breeding between years. On the Poe Reach, mainstem flow and water temperature were different between years, and on the Cresta Reach only water temperature was different between years; flow was nearly the same (343.2 cfs versus 349.5 cfs). These results suggest that the timing of breeding is a hierarchical response where day length initiates frog movements to the river, but a combination of mainstem temperature and flow level determines the ultimate breeding date.

Breeding was initiated approximately 22 days later on the Cresta Reach compared to the Poe Reach in 2004, a pattern consistent with previous survey data from these reaches (GANDA 2003a, GANDA 2003b). However, none of those previous years included extended periods of high flows during the breeding season. During previous studies, females were documented initiating breeding as early as April 10 and as late as May 15 on the Poe Reach, and on the Cresta Reach as early as May 17 (in 2004) and as late as May 27 (GANDA 2003b). These observations provide additional evidence that day length is the factor that determines when frogs initiate movements to mainstem river breeding sites, and temperature and flow are the factors that determine when breeding occurs.

Two other factors were discovered that apparently affect the timing of breeding and movement. Skewed sex ratios, such as those observed on the Cresta Reach where few to

no males were observed, apparently delayed females from breeding. It is also suspected that if males were present in greater numbers, breeding would have been initiated earlier. The relationship between the sizes of female frogs relative to their breeding date was also explored. For Tributary 6c, where the largest sample of frogs was available for analysis, researchers observed a strong negative relationship between frog size and date of breeding. The implication is that older frogs may be responding earlier to innate (hormonal) cues or experience.

General frog movement and breeding patterns were probably influenced by other factors unrelated to environmental conditions. Social behavior plays an important role in establishing the general framework for frog breeding activity (Wells 1977). Of the two general categories described by Wells (1977: prolonged breeding and explosive breeding), foothill yellow-legged frogs on the Feather River appear to fit into the explosive breeding category, due to their relatively short breeding period (9 to 45 days during this study) and spatially clumped oviposition sites. Ecological factors, such as predation, may also play an important role in determining breeding and movement patterns. For example, four adult female foothill yellow-legged frogs were found that were eaten by aquatic garter snakes (*Thamnophis couchii*) during the brief time they were present at breeding sites on the mainstem river. Because of this predation pressure, females are apt to spend less time on the river. In addition, female frogs are potential predators of males, based on their size advantage (spent females mean weight was 31 g versus males 15.8 g), and the whereabouts of male frogs prior to the breeding season, especially in the Cresta Reach, is uncertain and possibly influenced by female territories on tributaries.

During the first week of April 2004, PG&E conducted a flow study to evaluate the effects of flow level on foothill yellow-legged frog breeding habitat area. This study produced increased flows ranging from 300 to 2000 cfs over a 10-day period on the Poe Reach. These flows apparently did not alter frog movement or breeding patterns; however, the last and greatest magnitude flow event occurred 17 days prior to the onset of breeding in this reach. During the period when these flows occurred, several male frogs and at least two gravid female frogs were observed on the mainstem river near breeding sites. In 2005, high flows (~5000 cfs) during a three-week period in May apparently prevented frogs from breeding, despite their presence at river breeding sites.

During the period of high flows in 2005, the research team monitored several radio-tagged frogs that were on the mainstem river. One male who arrived on March 23 experienced flows ranging from approximately 110 to > 15,000 cfs, but was unharmed. The response of that particular frog and others present during high flows was to utilize edgewater areas, where flow velocity was moderate.

4.2. Commercialization Potential

Results of this study may be used to develop management recommendations for hydroelectric power generators to manage for sensitive wildlife species. Findings on the

environmental cues for breeding in the foothill yellow-legged frog will help managers develop triggers to mimic the natural hydrograph and determine appropriate timing of recreation flows and pulse flows. By understanding the factors associated with foothill yellow-legged frog breeding activity, hydropower operators may be able to positively influence the survival of the species.

4.3. Recommendations

These findings suggest that the date female frogs initiate movement to mainstem river breeding sites is predictable based on day length. Most female frogs will be moving toward the river during early May. High flows on the mainstem, whether they are natural spring pulses or manufactured flow releases, apparently do not affect this pattern.

The date that frogs breed is more variable between years and is based partly on environmental conditions. Careful understanding of these factors and manipulation of river discharge levels can enhance breeding success in years of high flows. Although, substantial variability in the time of breeding was observed, it may be possible to predict when frogs will breed and manipulate flows levels to enhance breeding success. For example, on May 18, 2005, water temperature was ≥ 10°C and flows were approaching base flow following a brief period of flows in the range of 3000 cfs. At this time, at least one frog laid eggs that were subsequently scoured when flows increased the following day and were maintained at high levels for a three-week-long period. It is predicted that flows sustained above 500% of base flow would delay frogs from breeding and possibly result in their successful breeding at a later date when flow levels have truly peaked for the year and danger of scouring from rapid changes in flow level has passed.

These data suggest that extending the declining limb of spring pulse flows in a manner that will prevent rapid changes in river discharge might be employed as a conservation measure to increase breeding success in foothill yellow-legged frogs. Based on data collected during this study, hydroelectric power operators can use their extensive knowledge of snow pack and precipitation records to predict and modify flow levels to delay breeding. In the case of the early breeding frogs in 2005 (see Figure 7), hydroelectric power operators could have maintained high flows during the period when frogs initiated breeding. High flows would likely have prevented some or all of those frogs from breeding at that time, providing them an opportunity to successfully breed after the threat of high flows had passed.

4.4. Benefits to California

This research provides direct benefits to the people of California. Information gained through this study will be published in a peer-reviewed journal providing important information to biologists, natural resource managers, and hydroelectric power plant operators. Biologists will have access to detailed information on critically important life history traits of this increasingly rare species. Natural resource managers, including the California Department of Fish and Game and the U.S. Fish and Wildlife Service, will

benefit from this information as it pertains to their mission to preserve and protect the state's and the nation's natural resources. This information will benefit hydroelectric power operators by enabling them to understand the influence of pulsed flow releases and flow fluctuations on frog movement patterns. This work is especially relevant at this time when many hydroelectric projects are in the process of relicensing and reviews are being conducted on the current management of regulated rivers. Finally, the people of California benefit from this research because the information will contribute to preservation and knowledge of the species, which is a unique part of California's natural heritage.

5.0 References

Ashton, D. T., A. J. Lind, and K. E. Schlick. 1998. Foothill yellow-legged frog (*Rana boylii*) natural history. USDA Forest Service, Pacific Southwest Research Station, Arcata, California. 18 pp.

Duellman, W. E., and L. Trueb. 1986. *Biology of amphibians.* The John Hopkins University Press, Maryland.

Fukuyama, K., and T. Kusano. 1992. "Factors affecting breeding activity in a stream-breeding frog, *Buergeria buergeri*." *Journal of Herpetology* 26: 88–91.

Garcia and Associates (GANDA). 2003a. *Results of 2003 surveys for Foothill Yellow-legged Frog* (Rana boylii) *within the Poe Powerhouse Project Area, North Fork Feather River.* October 2003. Draft report prepared for Pacific Gas and Electric Company.

Garcia and Associates (GANDA). 2003b. *Results of 2003 surveys and monitoring for foothill yellow-legged frog* (Rana boylii) *within the Rock Creek-Cresta Project Area, North Fork Feather River, Recreation and Pulse Flow Biological Evaluation.* Report prepared for Pacific Gas and Electric Company. November, 2003. 64 pp. plus appendices.

Garcia and Associates (GANDA). 2004. *Results of 2004 study evaluating impacts of elevated flows on foothill yellow legged frog* (Rana boylii) *habitat in the Poe Reach, North Fork Feather River.* Draft Report to Pacific Gas and Electric Company, San Ramon, California.

Garcia and Associates (GANDA). 2005. *Results of 2004 surveys and monitoring for foothill yellow-legged frog* (Rana boylii) *within the Rock Creek-Cresta Project Area, North Fork Feather River, and 2002-2004 Recreation and Pulse Flow Biological Evaluation Summary.* Data report prepared for Pacific Gas and Electric Company. July 2005. 89 pp. plus appendices.

Gosner, K. L. 1960. "A simplified table for staging anuran embryos and larvae with notes on identification." *Herpetologica* 16: 183–190.

Jennings, M. R., and M. P. Hayes. 1994. *Amphibian and reptile species of special concern in California.* Final report to the California Department of Fish and Game, Inland Fisheries Division, Rancho Cordova, California. 225 pp.

Kupferberg, S. J. 1996. "Hydrologic and geomorphic factors affecting conservation of a river-breeding frog (*Rana boylii*)." *Ecological Applications* 6(4): 1332–1344.

Lind, A. J., H. H. Welsh, Jr., and R. A. Wilson. 1996. "The effects of a dam on breeding habitat and egg survival of the foothill yellow-legged frog (*Rana boylii*) in northwestern California." *Herpetological Review* 27(2): 62–67.

Muths, E. 2003. "A radio transmitter belt for small ranid frogs." *Herpetological Review* 34(4): 345–348.

Scheiner, S. M., and J. Gurevitch. 2001. *Design and Analysis of Ecological Experiments* (second ed.). Oxford University Press: Oxford, New York.

Stebbins, R. C. 2003. *A Field Guide to Western Reptiles and Amphibians* (third ed.). Houghton Mifflin Company: Boston and New York.

Watson, J. W., K. R. McAllister, D. J. Pierce, and A. Alvarado. 2000. *Ecology of a remnant population of Oregon spotted frogs* (Rana pretiosa) *in Thurston County, Washington.* Final Report. Washington Department of Fish and Wildlife, Olympia, Washington, USA.

Wells, K. D. 1977. "The social behavior of anuran amphibians." Smithsonian Tropical Research Institute. *Animal Behavior* 25: 666–693.

Yarnell, S. M. 2000. The influence of sediment supply and transport capacity on foothill yellow-legged frog habitat, South Yuba River, California. Masters Thesis, Department of Geology, University of California, Davis. 113 pp.

Zweifel, R. G. 1955. "Ecology, distribution, and systematics of frogs of the *Rana boylei* group." University of California Publications in *Zoology* 54: 207–292.

6.0 Glossary

amplexus	The mating posture of frogs and toads.
anuran	An amphibian with long hind legs and with no tail at maturity.
cfs	cubic feet per second
FERC	Federal Energy Regulatory Commission
GANDA	Garcia and Associates
NFFR	North Fork Feather River
oviposition	The process of laying eggs.
PG&E	Pacific Gas and Electric
SD	standard deviation
SUL	snout-urostyle length

Appendix A. Tributary Descriptions

Appendix A

Tributary Descriptions

This appendix describes pertinent habitat features for each of the six tributary sites based on information gathered during the study.

Tributary 1a

Tributary 1a is located adjacent to the Shady Rest Area along Highway 70 on the Cresta Reach. The total site length is 296 meters (m). A 30 m culvert runs under Highway 70 to connect the tributary to the left bank of the mainstem North Fork Feather River (NFFR). Another 15 m of habitat is accessible to survey below the culvert. Due to the culvert and two large waterfalls, total accessible survey area is approximately 244 m. The survey area ends at a large waterfall preceded by a narrow (1 m wide) bedrock channel. The staff gage was installed at 55 m, approximately 10 m above the culvert. Flow was 2.1 cubic feet per second (cfs) in April 2004. Average wetted channel width was 2–3 m and, stage height dropped 6.5 centimeters (cm) between early April and July 1, 2004. No dry sections occurred within the survey area during the course of the study. Substrate consisted primarily of boulder, bedrock, and cobble, and there was a high percentage of aquatic and terrestrial cover. Vegetation at the margins was relatively dense and included California blackberry (*Rubus ursinus*), alder (*Alnus* sp.), willow (*Salix* sp.), and elephant ear (*Darmera peltata*). There are several cascade pools (3–4) along the survey site and creek gradient varies from moderate in the lower section to low gradient near the upper portion of the site. Elevation increases from 455 m (1500 feet) at the confluence to approximately 535 m (1760 feet) at the top of the survey site. Bank gradients along this tributary are moderate to high. Two breeding sites are associated with this tributary. A lateral cobble bar (231 m in length) situated on the right bank of the main stem, directly across the river from the Shady Rest stop area and, a point bar (141 m in length) situated on the left bank located upstream of the tributary and just downstream of Arch Rock Tunnel.

Cedar Creek

Cedar Creek is located approximately 1200 m downstream from the Shady Rest area on the right bank of the NFFR on the Cresta Reach. A steep and inaccessible waterfall, 79 m in length, makes up the bottom portion of the tributary to the confluence with the main stem. A railroad culvert (estimated to be approximately 60 m in length) at the top of the waterfall channels the tributary, and the survey site begins at the top of that culvert. Total site length is 248 m and the top of the site ends at the base of a tall (~15 m) waterfall preceded by a small bedrock and boulder pool. Total habitat area accessible for survey is 238 m because of a small waterfall obstacle. The staff gage was installed at 16 m above the top of the railroad culvert. Average wetted channel width for this tributary is approximately 3 m, and stage height dropped approximately 21 cm from

mid-April to early July in 2004. Flow was 2.7 cfs in April 2004. No dry sections occurred within the survey area during the course of the study. Vegetation at the margins was moderately dense and consisted of alder, willow, and oaks (*Quercus* sp.). Substrate consists primarily of bedrock and boulder with some sand/gravel areas. Bank gradients along Cedar Creek vary from moderate to high. There are several small waterfalls along the site with cascade pools. Overall gradient change for this tributary is moderate. Elevation increases from 425 m (1400 feet) at the confluence to approximately 535 m (1760 feet) at the end of the survey site. Two breeding sites are associated with Cedar Creek: a small (27 m in length), low-gradient lateral cobble bar is located approximately 300 m downstream of the confluence on the right bank, on the left bank approximately 277 m downstream from the confluence is a low-gradient lateral cobble bar (77 m in length).

Tributary 9ae

Tributary 9ae is located approximately 350 m downstream of Cedar Creek on the right bank of the main stem NFFR on the Cresta Reach. A railroad culvert (approximately 129 m in length) connects the tributary to the mainstem and divides the survey site into two sections. Total site length is 265 m with 114 m of survey area below and 151 m above the culvert and the upstream portion ends at a moderately steep and wide bedrock waterfall preceded by a long (~7 m) pool. Total accessible survey length is 232 m due to three waterfall obstacles. The staff gage was installed at 41 m above the mainstem. Average wetted channel width for this tributary is approximately 3 m and, during the course of the study, stage height dropped only 3 cm from mid-April to early July in 2004. Flow was 1.5 cfs in April 2004. No dry sections occurred within the survey area. Vegetation at the margins was moderate to high and consisted of California blackberry, alder, willow, and elephant ears. Substrate consists primarily of boulder, bedrock, and cobble. Overall gradient change for this tributary is moderate, but bank gradient is high. Elevation increases from 425 m (1400 feet) at the confluence to approximately 535 m (1760 feet) at the end of the survey site. There are two breeding sites associated with Tributary 9ae: a small (27 m in length), low-gradient lateral cobble bar on the right bank immediately downstream from the confluence and, a low-gradient lateral cobble bar (77 m in length), located on the left bank, directly across the river from the confluence. These are also the breeding sites for frogs from Cedar Creek.

Flea Valley Creek

Flea Valley Creek is located in the Poe Reach of the NFFR approximately 1600 m downstream of the Poe Dam on the right bank. There are two culverts on this tributary, a railroad culvert approximately 74 m upstream of the confluence, and a road culvert at about 390 m. Both culverts are low gradient and do not present an obstacle. Total site length is 613 m. The staff gage was installed at the top of the survey area at 613 m. The average wetted channel width is 3 m, and during the course of the study, stage height decreased by only 4 cm. Flow was 3.3 cfs in April 2004. No dry sections occurred within the survey area. There are numerous (15–20) main channel pools along the survey reach.

Vegetation at the margin was relatively dense, and terrestrial and aquatic cover values were also high, with mostly vegetation, boulders, and undercut banks. Bank gradient is moderate, and stream gradient is low to moderate. Elevation increases from 410 m (1340 feet) at the confluence to approximately 465 m (1520 feet) at the end of the survey site. The stream aquatic habitat changes several times, alternating between riffle/pocket water and pocket water/cascade habitats. Substrate consists primarily of boulder, cobble, and some bedrock. Four breeding sites are associated with Flea Valley Creek. A boulder/sedge margin (72 m in length) approximately 10 m downstream from the confluence along the right bank and, immediately upstream of that site, is a cobble/boulder lateral bar (50 m in length) along the right bank that meets the confluence of the tributary. Just upstream of the confluence is a broad, lateral cobble/boulder bar (87 m in length) on the right bank. Finally, directly opposite the confluence of Flea Valley Creek is a low-gradient lateral cobble/boulder bar (137 m in length) located on the left bank NFFR.

Tributary 5a

Tributary 5a is located in the Poe Reach of the NFFR approximately mid-way between Bardees Bar and Swimmer's Beach. A short culvert connects the tributary under Bardees Bar Road but the upper portion of the survey area ends at the base of the road culvert. Total survey length for Tributary 5a is 830 m. The staff gage was installed at 821 m, approximately 9 m below the culvert. Average wetted channel width was 1 to 3 m wide and, during 2004, stage height decreased 10 cm, leaving the staff gage pool completely dry by July 1. Flow was 0.2 cfs in April 2004. There was a long dry section at the base of the tributary that increased from 162 m on April 11, 2004 to 340 m during the July 8, 2004 survey. Margin vegetation was moderate, but terrestrial cover was high and varied, including rootwad, vegetation, logs, boulders, burrows, woody debris, and leaf litter. Aquatic cover was moderate and mostly composed of crevices between boulders. Substrate consists primarily of boulder and cobble. Bank gradient was high, and stream gradient was moderate to high. Elevation increases from 280 m (920 feet) at the confluence to approximately 450 m (1,480 feet) at the end of the survey site. The breeding site associated with Tributary 5a is a low-gradient, mid-channel, cobble/gravel bar with a wide, braided channel along the right bank. The site length is 88 m in length and ranges from 5 to 10 m in width.

Tributary 6c

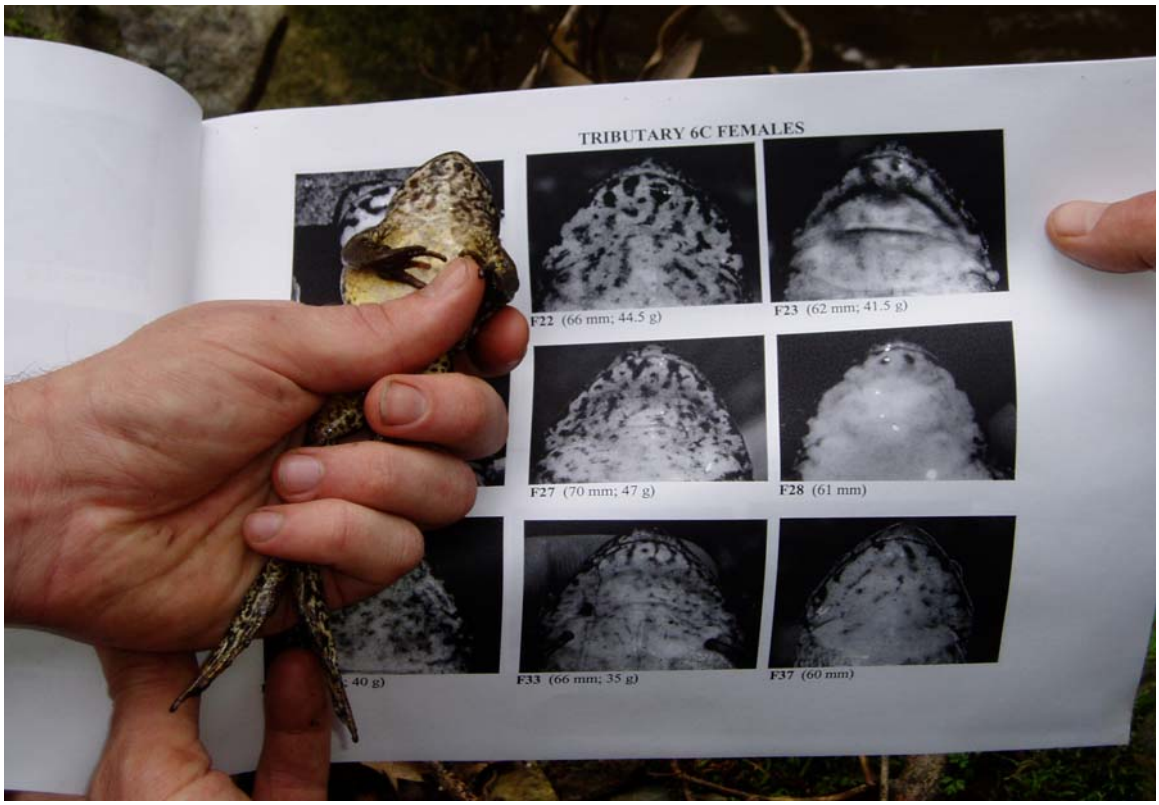
Tributary 6c is located in the Poe Reach of the NFFR approximately mid-way between Bardees Bar and Swimmer's Beach and approximately 400 m downstream from tributary 5a. A short culvert connects the tributary under Bardees Bar Road; however, the survey area ends at the base of this culvert. Total survey length for Tributary 6c is 1454 m, the longest survey site in the study. The staff gage was installed at 1447 m from the NFFR confluence, approximately 7 m below the culvert. Average wetted channel width was 2 m wide and, during the course of the study, stage height decreased gradually, and only by 3 cm, from early April to July 1, 2004. Flow was 0.1 cfs in April

2004. One dry section occurred within the survey area, between approximately 450 and 650 m. Vegetation at the margins was moderate to high and consisted of spicebush (*Calycanthus occidentalis*), dogwood (*Cornus nuttalli*), alder, vine maple (*Acer circinatum*), California grape (*Vitis california*), sword fern (*Polystichum* sp.), bee plant (*Cleome* sp.), California blackberry, Himalayan blackberry (*Rubus discolor*), buckeye (*Aesculus californica*), pinion pine (*Pinus edulus*), Douglas fir (*Pseudotsuga menziesii*), elk clover (*Aralia californica*), black maple (*Acer nigrum*), elderberry (*Sambucus nigra*), live oak (*Quercus virginiana*), black oak (*Quercus velutina*). Aquatic and terrestrial cover values were moderate and included gaps in substrate, leaves, and woody debris. A forest fire in 2001 opened the canopy in the middle-to-upper portions of the reach and has littered the creek with burned logs and fallen trees. Creek gradient is mostly high throughout the reach but includes sections of low and moderate gradient. Elevation increases from approximately 275 m (900 feet) at the confluence to approximately 560 m (1845 feet) at the end of the survey site. Bank gradient is high throughout and active bank erosion is evident. There are two breeding sites associated with Tributary 6c. The first one is a low-gradient, left bank boulder/cobble bar (150 m in length) directly opposite the confluence. The second site, a low-gradient lateral bar, pool tail-out and side channel area (110 m in length) on the right bank, is located approximately 160 m downstream of the confluence.

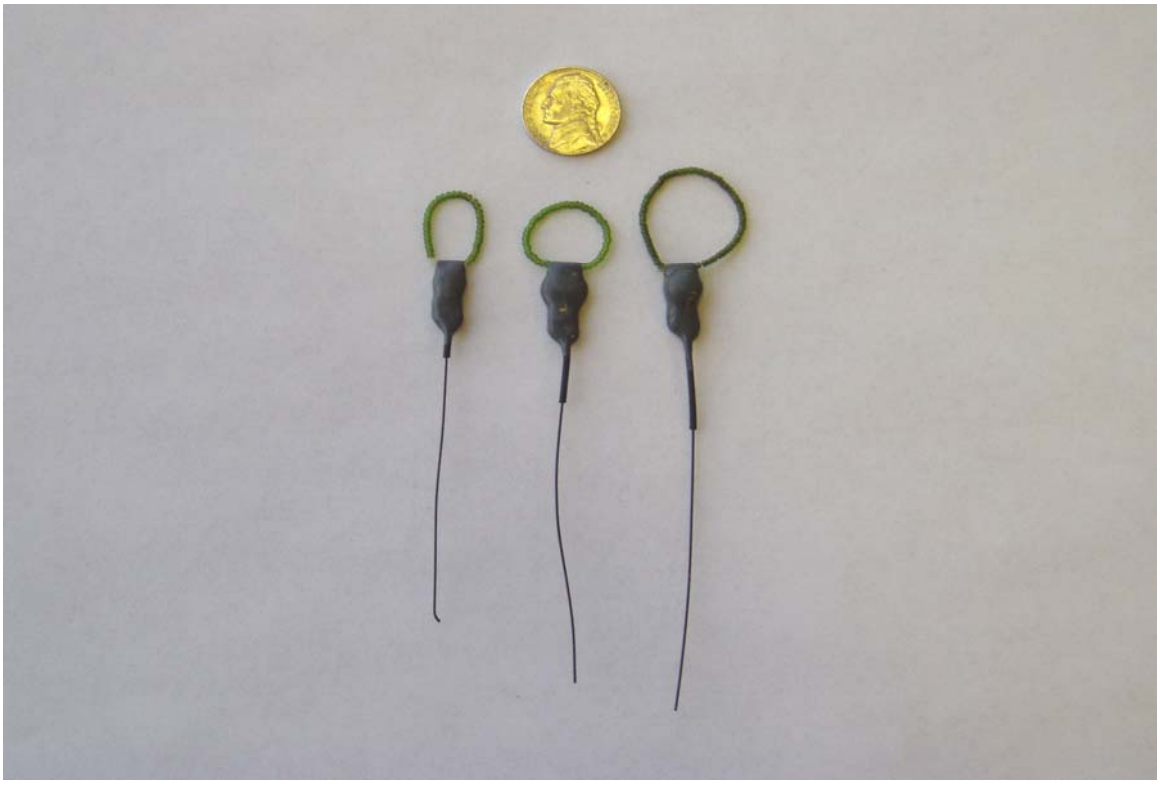
Appendix B.

Representative Photos of Frog Activities, Locations, Habitat, and Chin Patterns

Male *Rana boylii* (6c-M46) fitted with transmitter 2-15-05
Photo No: REJ2150006



Identifying individual frogs in the field in 2005. This female frog matched 6c-F22 from 2004. 2-17-05
Photo No: REJ2170037



Holohil BD-2 transmitters (0.90 g, 1.6 g, 1.8 g, from left to right) fitted with attachment belts. 1-10-06
Photo No: KDW 1100121

Radio-tagged frog (6c-F126) found in leaf litter 1m above creek 4-12-05
Photo No: KRM4120048

Frog basking (arrow) on vertical wall approximately 2 m up from water on Tributary 6c 5-4-05
Photo No: KDW5040073

Gravid female frog (CED-F5) found underwater on river 5-28-05
Photo No: KRM5280011

Radio-tagged male frog (FVC-M13) hidden in crevice between two boulders on river bank 3/21/05
Photo No: KRM3210014

Microhabitat of FVC-M13 (above) location approximately 5 m from edgewater on river bank 3/21/05
Photo No: KRM3210017

Radio-tagged male (6c-M52) in amplexus with unidentified female on river breeding site 5-4-05
Photo No: KRM05040017

Eggmass at Gosner stage 8 in location of amplexus (above) 48 hours later 5-6-05
Photo No: KRM05060030

Radio-tagged female (CED-F5) in amplexus with male (9e-M5) 6/2/05
Photo No: KRM06020166

Fresh eggmass from CED-F5 and 9e-M5. Frogs still in amplexus in foreground. 6/2/05
Photo No: KDW06020071

Frog in culvert on Tributary 6c 3/23/05
Photo No: KRM3230122

Frog in culvert on Tributary 1a under Highway 70 4/5/05
Photo No: KRM4050070

Tributary 1a culverts at Highway 70, downstream end. 4/5/05
Photo No: KRM04050055

Tributary 6c culvert just below Bardee's Bar Road. 3/30/05
Photo No: PFP 006

Waterfall on Cedar Creek near confluence with the North Fork Feather River (foreground). 4/06/05
Photo No: P4060076

Dry section of Tributary 5a just upstream of confluence with the North Fork Feather River. 5/10/04
Photo No: REJ 5d04 DSCF0041

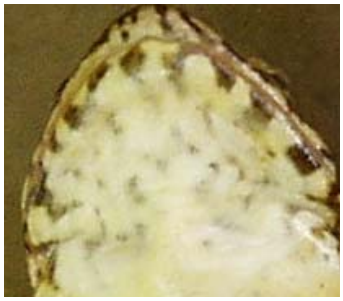
Ten chin photographs of a female frog (6c-F103) from Tributary 6c observed during Feb. to June 2005.

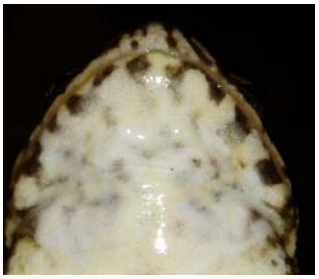
2/15/05

3/15/06

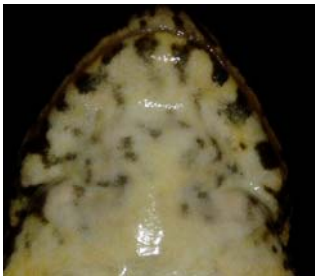
4/6/05

4/25/05


5/2/05


5/4/05

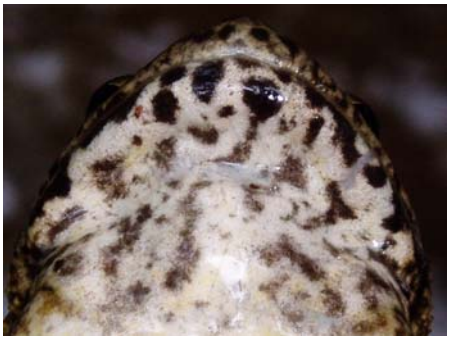
5/22/05

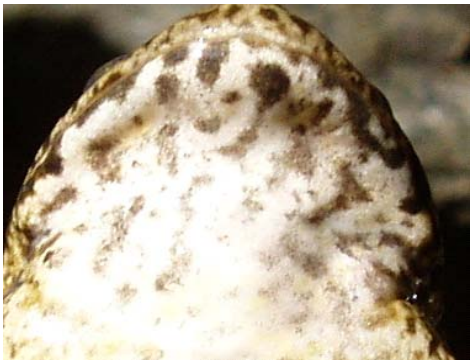

6/1/05

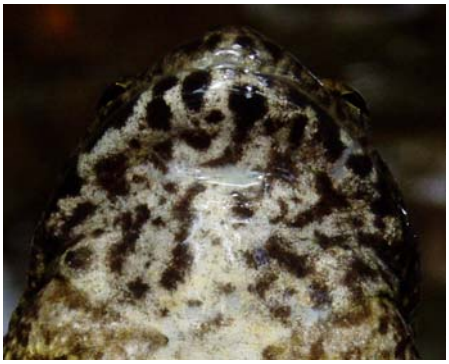
6/6/05

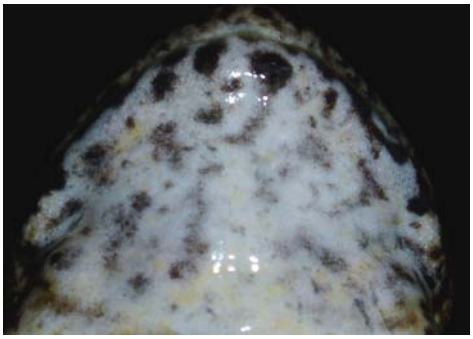
6/11/05

Seven chin photographs of a female frog (6c-F22) from Tributary 6c observed multiple times each year.

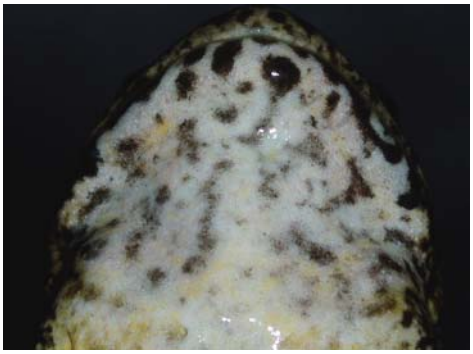

5/8/04


4/12/05


5/10/04


5/16/05

5/14/04


6/1/05

2/17/05