

ECOLOGICAL ASPECTS OF
FOOTHILL YELLOW-LEGGED FROGS (*RANA BOYLI*) IN THE
DIABLO MOUNTAIN RANGE ON
UPPER COYOTE CREEK IN SANTA CLARA COUNTY, CA

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By

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The Designated Thesis Committee Approves the Thesis Titled

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ABSTRACT

ECOLOGICAL ASPECTS OF FOOTHILL YELLOW-LEGGED FROGS (*RANA BOYLI*) IN THE DIABLO MOUNTAIN RANGE ON UPPER COYOTE CREEK IN SANTA CLARA COUNTY, CA

by Thomas E. Gonsolin, Jr.

Knowledge of ecological aspects of foothill yellow-legged frogs is lacking for the central and southern Coast Ranges in California. I used visual encounter surveys (VES), mark and recapture and biotelemetry to collect data on breeding, movement, growth, habitat use and preferences and presence of diurnal predators for a species in decline through much of its range. This study may aid resource managers develop conservation plans that are compatible with land and water use by humans. This study was conducted on upper Coyote Creek in Santa Clara County, California, from March 2004 to March 2006. A total of 182 frogs were marked and 106 were re-captured during 2004-2005. Three adult females and two males were telemetered during summer and early fall 2005. I conducted 215 VES surveys and all sites were surveyed at least 60 times during the study.

Breeding initiation was similar during 2004, 2005 and 2006 at two sites. The 2005 breeding season lasted a few weeks longer than in 2004, which was a drier year. Nineteen more egg masses were deposited in 2005 than 2004. This is attributable to prolonged favorable breeding conditions from greater runoff in 2005 compared with 2004. All breeding occurred on descending limbs of the hydrograph and egg masses were deposited at stream flows less than an order of magnitude greater than spring base flows.

Water temperatures were near 12°C at breeding initiation during all three years. Peak breeding was between 13 and 16°C and did not occur at temperatures above 20.5°C during 2005, when water temperatures were recorded hourly throughout the year. In general, egg mass size decreased as the breeding season progressed during 2004 and 2005. However, the trend was more pronounced in 2005, because 2004 cohort females were able to spawn during the prolonged breeding season as yearlings. Breeding frogs used oviposition locations closer to shore, in deeper water and occasionally used submerged vegetation in 2005 compared with 2004.

Adults of both sexes made significant movements to and from the breeding areas from early March to mid-May, 2005. Males tended to arrive at breeding areas earlier and stay there longer than females. Resident tributary frogs moved greater distances than their mainstem counterparts. On average, females tended to travel further than males and they occupied resident habitats further from the breeding areas. Adult frogs did not move from their resident habitats unless channel dry backs necessitated it, or rain events created opportunities to move over dry channels to alternative perennial habitat during the non-breeding season. The 2004 cohort stayed in their natal habitats through summer and most of fall until early winter rains re-established continuous flow in mid-December 2004. No discernable patterns of movement (upstream vs. downstream) could be detected.

Biotelemetry showed that VES detect frogs about one third of the time on average. Frogs that used larger substrates, heads of pools or were underwater or substrate were much harder to detect with VES. Frogs on upper Coyote Creek exhibited greater growth during their first year compared to Sierra Nevada and north Coast Range populations. The 2004

cohort all grew to a SVL greater than 40 mm prior to the end of the 2005 breeding season in mid-May.

Both sexes preferentially used pools on both the mainstem and Dexter Creek. Females also used flatwater habitats preferentially on the mainstem. Females and males preferred boulder dominated habitat and did not use sand dominated habitat. Males used cobble and gravel dominated habitats on the mainstem and also used gravel dominated habitats preferentially Dexter Creek. Females used habitats with greater escape cover complexity on the mainstem and Dexter Creek and habitats with greater depth on Dexter Creek. There were far more observed diurnal predators on the mainstem (90 percent) than on the tributary Dexter Creek. Santa Cruz garter snakes were the most encountered predator within the study area (60 percent). California red-legged frogs comprised most of the potential predators on Dexter Creek. No avian and few reptilian predators were observed on Dexter Creek. Illegal marijuana cultivation by Mexican organized crime organizations were the greatest threat to the population. Four tributaries within the study area that had foothill yellow-legged frogs were utilized. Perennial water is the limiting factor within the study area, so any water diversions, legal or otherwise pose a serious threat to this population.

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I dedicate this project to my family and friends, who were supportive of my work throughout the entire process. In addition, I dedicate my efforts to future researchers of *R. boylei*. My hope is this thesis will help them during all phases of their work. Much more focused research needs to be conducted to increase our understanding of a species in decline and help guide conservation measures that will allow the species to persist and perhaps reestablish populations in watersheds where they have been extirpated.

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ACRONYMS

°C	degrees Celsius
Bd	<i>Batrachochytrium dendrobatidis</i>
cfs	cubic feet per second
cms	cubic meters per second
FERC	Federal Energy Regulatory Commission
ft	feet
g	grams
km	kilometers
m	meters
mi	miles
mm	millimeters
mps	meters per second
mtDNA	mitochondria DNA
SCCOSA	Santa Clara County Open Space Authority
SVL	snout to vent length
VBGE	Von Bertalanffy Growth Equation
VES	visual encounter surveys

Foothill yellow-legged frogs (*Rana boylei*) are one of four native, ranid species which reside in California (Stebbins 2003). It is unique among these ranids in its exclusive association with running waters to complete its lifecycle. The current status and distribution of foothill yellow-legged frogs is not entirely known. Populations have disappeared throughout their historic range, particularly on the west slope of the Sierra Nevada foothills and southern Cascades. Due to the declines and stream habitat requirements of foothill yellow-legged frog, these frogs have become a focal species in Federal Energy Regulatory Commission (FERC) hydropower relicensing projects (Lind et al. 2008).

Potential causes of decline are numerous. They include: reservoir and road construction, reservoir operations, logging, water quality degradation and non-native predators. Predation by introduced fish and bullfrogs (*Rana catesbeiana*) has been blamed for foothill yellow-legged frog declines (Moyle 1973, Hayes and Jennings 1986, Jennings and Hayes 1988, Kupferberg 1996a, Ashton and Nakamoto 2007, Ashton 1998). Foothill yellow-legged frog declines have been part of a more general decline in amphibians in the western United States. Studies have implicated solar UV-B for amphibian declines in the western US (Blaustein 1994a). Pesticide drift from the Sacramento and San Joaquin Valleys has been argued as a factor in ranid declines in the Sierra Nevada (Drost and Fellers 1996, Davidson et al. 2002). Large die offs of amphibians from chytrid fungus have been documented in California (Fellers 2001), and other pathogenic fungi contribute to amphibian losses in the Western US (Blaustein et al. 1994b).

Although there is no evidence for a singular range wide cause for foothill yellow-legged frog declines, there are many studies that have associated the presence or absence of this species with physical habitat parameters of their streams and rivers which include flows, substrate and canopy coverage (Zweifel 1955, Hayes and Jennings 1988, Van Wagner 1996, Kupferberg 1996b, Yarnell 2000, Ibis Environmental Inc. 2002). Effects of flow fluctuations on breeding habitat and egg survival were studied on the Trinity River (Lind et al. 1996). Geomorphic and hydrologic factors on habitat suitability have been studied in the Sierra Nevada (Kupferberg 1996b, Yarnell 2000).

However, some life history aspects of foothill yellow-legged frogs are not well understood. There are no publications regarding movement and dispersal of foothill yellow-legged frogs during different life history stages (Jennings and Hayes 1994, Ashton 1998). There have been no studies to date, documenting winter habitat use. No studies of any kind have been published on foothill yellow-legged frogs in the Coast Ranges south of San Francisco.

To address the knowledge gaps on movements and habitat use by foothill yellow-legged frogs I investigated habitat preference of adults in a partially intermittent stream reach in the Mt. Hamilton range south of San Francisco Bay, within a poorly studied region within this species range in the Central Coast of California. I collected data on breeding locations and timing in association with stream flow and water temperatures at two breeding sites within an understudied region of this species range, the Central Coast of California. This study may give insight to factors in declines of foothill yellow-legged frogs at the watershed level, particularly on streams altered by water diversions or with

natural low summer flows. A study determining seasonal movement patterns and habitat utilization may also aid government agencies and land managers to enact measures for conservation of this species.

Specific Aims

My objectives for this study were to quantify:

1. Timing of breeding, breeding habitat utilization and physical environment associated with breeding.
2. Timing, duration, and magnitude of seasonal movements using radiotelemetry and tagging studies of foothill yellow-legged frogs in relation to streamflow fluctuation and water temperatures.
3. Seasonal habitat use parameters such as: mesohabitat type (i.e. pool, riffle run), mesohabitat maximum depth, cover complexity, substrate composition, and canopy closure.

Literature Review

Species Description

The foothill yellow-legged frog is a medium sized frog, with adults ranging in length from 37.2-82.0 mm snout to vent (SVL) (Jennings and Hayes 1994). This species is sexually dimorphic at maturity, with females averaging 10-20 mm longer (SVL) (Zweifel 1955). Adult males have darkened and swollen thumb bases and relatively muscular forearms. Dorsal coloration of this species is variable, but is typically mottled light and dark brown, gray or olive, and sometimes with brick red to match the local substrate. The

ventral surface of the hind legs is yellow, usually extending to the lower abdomen then fading to white (Jennings and Hayes 1994). The dorsal surface of the hind legs of adults has dark colored bands. Typically, there is dark brown mottling on the ventral surfaces where yellow pigment is absent. Yellow and dark mottling ventral coloration is not present or is faint in juveniles. They are also distinguished from other frogs and toads by the absence of black eye mask, horizontal pupils, fully webbed hind feet, weakly developed dorsal lateral folds, obscure tympanum, and lack of a dorsal stripe as in California red-legged frogs and a strong tendency to jump into flowing water to escape (Stebbins 2003).

Tadpoles are small and black when they hatch and are difficult to distinguish from western toads (*Bufo arboreus*) without magnification of mouth parts (Ashton 1998). Their dorsal coloration transforms to olive with irregular brown mottling as they grow. Ventral surfaces appear silvery and almost opaque with the viscera scarcely visible. Tadpoles have a rather flattened body, downward oriented mouthparts, and dorsal ventrally reduced tail (i.e., height) compared with other ranids, which may be adaptations suited to flowing water (Zweifel 1955, Nussbaum 1983). Egg masses are up to fist size and resemble a cluster of grapes (Stebbins 1985).

Distribution and Status

Historically, foothill yellow-legged frogs occupied most permanent streams in the Coast Ranges from southern Oregon to the San Gabriel Mountains and the foothills of the southern Cascades and Sierra Nevada to the Tahacapi range (Jennings and Hayes 1988). It was the most common amphibian encountered in the Rogue River Valley in the early

1900s (Fitch 1938). Isolated populations were reported in San Pedro Matir in Baja California, Elizabeth Lake Canyon in Los Angeles County and Sutter Buttes in Butte County, California (Stebbins 2003). The elevational range of this frog extends from sea level to 1,400 m (4,500 feet [ft.]) in the Sierra Nevada. Temperatures are likely too cold and the growing season too short to provide sufficient resources for embryos to reach metamorphosis before the onset of winter above 4,500 ft (Placer County Water Agency 2008). Currently, this frog is found from southern Oregon to the Salinas River watershed and coastal Big Sur and San Luis Obispo watersheds in the Coast Ranges and from the west slope of the Cascades in Oregon to the southern Sierra Nevada (Jennings and Hayes 1994). Large populations appear only in the North Coast ranges from Oregon to Sonoma County. Scattered remnant populations remain elsewhere within its historic distribution, but foothill yellow-legged frogs appear to be extinct in the extreme southern portions of its historic range. Foothill yellow-legged frogs are no longer present in two thirds of their historic range in the Sierra Nevada and 45 percent of its historic range in California (Jennings and Hayes). Jennings (1996a) reported these frogs were absent from some locations in the Sierra Nevada foothills where Moyle (1973) found them to be plentiful. They were absent on all sites in the Yosemite area by Drost and Fellers (1996) where they were found by Storer (1925). They were considered to be endangered by Jennings and Hayes (1994) in the central and southern parts of their range. Accordingly, they are listed as a federal, USDA Forest Service and California species of concern and are fully protected by the state of California.

Lind (2005) used univariate and multivariate analyses to explore the spatial relationship between the current presence and absence of foothill yellow-legged frogs at historic sites relative to: geographic characteristics (e.g. elevation and latitude), land use impacts, wind borne toxins and pollutants, climatic factors and proximity and size of dams. Climatic factors showed the strongest influence in the multivariate analyses. Mean precipitation was positively correlated with presence and variability of precipitation and percent of dry years were negatively correlated with presence. In addition, Lind (2005) found that the negative impacts of dams were intensified in areas with low mean annual precipitation.

Reproduction and Life History

Adult frogs aggregate in the cobble dominated areas of streams in spring (Storer 1925, Zweifel 1955). Typically, breeding occurs from late March through May, and initiation of oviposition occurs as water temperatures increase to 12-15°C and as streamflows are decreasing near the end of the wet season (Zweifel 1955, Kupferberg 1996b, Fuller and Lind 1991, Seltenrich and Pool 2002). However, temperatures recorded on the Poe Reach of the Feather River during 2004 were close to 10°C during initiation of breeding (GANDA 2008). Warmer and drier than usual conditions in 2007 were likely the cause of observed early water temperature increases and initiation of breeding by foothill yellow-legged frogs two to three weeks earlier than typical across northern California (Placer County Water Agency 2008). (Kupferberg et al. 2007) concluded that breeding initiation is cued by increasing water and air temperature rather than stream flow. After seventeen years of monitoring on the South Fork of the Eel River, only a weak trend

towards breeding later in the year during wet years was observed (Kupferberg 1996a). In addition, shallow, low velocity margin area availability did not cue breeding. Oviposition may be postponed by rain once adults arrive in breeding areas.

Discrete populations may complete breeding within a two week period (Storer 1925, Zweifel 1955). Breeding season length on Hurdygurdy Creek in Del Norte County, CA varied between three to seven and a half weeks from 2002 to 2007 (Wheeler and Welsh 2008). Foothill yellow-legged frog behavior at Hurdygurdy Creek displayed prolonged rather than explosive breeding. Date within the breeding season and stream flow influenced breeding activity, rather than temperature (Wheeler and Welsh 2008). They concluded initiation and length of the breeding season was strongly influenced by the natural hydrologic cycle.

Mating calls from males generally occur underwater, but may be made above water (MacTeague and Northern 1993). Calls above water may be heard up to 50 meters (m) away (Ashton and Lind 1998). Females tend to select larger males for amplexus, as males in amplexus were larger than males never seen in amplexus (Wheeler and Welsh 2008). Males grasped onto females and were carried to the exact oviposition location of the females choosing. These locations were often different from the calling locations of the males.

Egg masses are usually found near stream margins in shallow pools, protected edgewater areas and pool tailouts most often associated with cobble/boulder bars at flow velocities of 0.0-0.21 m/sec and in water depths less than 0.50 m (Zweifel 1955, Hayes and Jennings 1988, Van Wagner 1996, Kupferberg 1996b). Breeding habitat preferred by

foothill yellow-legged frogs is typically shallow, near-shore areas of low velocity with cobble/boulder substrate in open, sunny areas with little riparian vegetation. These sites are often adjacent to low gradient cobble/boulder bars, tributary confluences, side and backwater pools, or pool tailouts with coarse substrates (Placer County Water Agency 2008). However, egg masses may be deposited in atypical habitat such as deep slack waters near pool heads or deep backwater pools, when preferred breeding habitat is not available (Seltenrich and Pool 2006). These areas provide the best protection from high fluctuating stream flows. Egg masses have not been documented to withstand flow velocities greater than 0.21 m/sec. Egg masses have been reported to be lost during high flow events (Lind et al. 1996). These high flow events may be the result of dam spills or releases or intense late spring storms. Egg masses are generally attached to the lee side of cobbles, large gravels and boulders, but woody debris and submerged vegetation may be used (Fuller and Lind 1991). Shallow waters with low velocities and large substrates represent the highest quality for oviposition sites and larvae (Lind et al. 2009).

Egg masses at oviposition are clear to blue, compact and gelatinous (Storer 1925). They soon absorb water, expand, lose blue coloration and resemble a grape cluster. Egg masses are generally plum size, but show wide size range (Storer 1925). An individual egg and its three gelatinous envelopes is about 5.4 mm in diameter (Storer 1925). Egg masses typically have about 200 to 300 eggs, but may vary between 100 and over 1,000.

Eggs may hatch from 5 to over 30 days from oviposition (Zweifel 1955). Researchers have found hatching to occur within 14 days in north Coast Ranges in California (Zweifel 1955, Kupferberg 1996a) and Southern Oregon (Nussbaum et al. 1983) and 31 days in the

Sierra Nevada (Van Wagner 1996). Slower development occurs with cooler temperatures (Ashton and Lind 1998). In the absence of disturbance, newly hatched tadpoles remain near egg masses for several days. Generally, metamorphosis takes place within three to four months and tadpoles do not overwinter. Larval development and growth in many amphibians has been correlated with water temperatures and food availability (Duellman and Trueb 1986). Maturation is achieved once foothill yellow-legged frogs reach 40 mm SVL (Zweifel 1955). Reproductive organs are active by their second summer, frogs were found to reproduce as early as six months after metamorphosis in the Central Valley (Jennings and Hayes 1988). However, breeding usually occurs when they are a full two years old (Zweifel 1955, Van Wagner 1996).

The life span of foothill yellow-legged frogs is unknown and little is known of amphibian life spans in the wild (Duellman and Trueb, 1986). Females tend live longer than males, which are often found to be three years or older (Zweifel 1955, Van Wagner 1996). In contrast, males were rarely found to be older than two years. However, males at least three or four years old were recaptured during a study on the North Fork Feather River and were the same size as three year old males at recapture (Drennan. pers. comm. 2008). Other species of ranids in the wild may live twelve or more years (Duellman and Trueb 1996).

Food Habits

Foothill yellow-legged frog tadpoles feed on algae and diatoms scraped from rocks and plants (Vollmar 2002). Tadpoles appear to have faster growth rates feeding on epiphytic diatoms and preferentially feed on them (Jennings and Hayes 1994). Tadpoles

may gather around other dead tadpoles, possibly to feed on dead tissue or algae and diatoms (Ashton 1998). Feeding ceases during metamorphosis, as the digestive system transforms to handle animal tissue and the tail is re-absorbed (Duellman and Trueb 1986). Once metamorphosis is complete, foothill yellow-legged frogs feed mainly on terrestrial invertebrates (Zeiner et al. 1988). Food includes ants, flies, hornets, grasshoppers, beetles, moths, snails and water striders (Nussbaum 1983). Van Wagner (1996) reported 90 percent of food eaten by these frogs was terrestrial arthropods, consisting of 87.5 percent insects and 12.6 percent arachnids. Ninety eight percent of frogs sampled on Cache Creek, a Clear lake tributary, had terrestrial arthropods in their stomachs (Hothem et al. 2009). Foothill yellow-legged frogs also eat aquatic invertebrates (Zeiner et al. 1988). Twenty eight percent of frogs sampled on Cache Creek had eaten aquatic arthropods (Hothem et al. 2009).

Habitat

Foothill yellow-legged frogs are found from small, ephemeral streams to large rivers within many types of plant communities including: valley-foothill hardwood, coastal scrub, chaparral, valley-foothill riparian, hardwood conifer, ponderosa pine and wet meadow (Stebbins 2003). Typically, they are found on cool, clear, shallow, slow flowing and rocky streams dominated by cobble substrates (Fitch 1938, Zweifel 1955). They have been reported to use streams with scarce cobble (Fitch 1938, Zweifel 1955), but this appears to be unusual (Jennings and Hayes 1994). Foothill yellow-legged frogs have been found in very atypical habitats which include; man-made tunnels, roadside culverts and along the banks of reservoirs (Peek and Khandwala 2006).

Foothill yellow-legged frogs prefer sunny banks with partial shading for basking (Jennings and Hayes 1994). Adults are typically seen on sunny banks in cascade, pool or riffle habitats near the waters edge. These frogs have been found using perennial pools of otherwise ephemeral tributary streams (Moyle 1973). However, they may be more susceptible to predation in these streams. Rearing habitat is similar to breeding habitat soon after embryos hatch, but tadpoles may move into shallow, warm, low velocity areas with smaller substrates (i.e., gravel/sand) later in the year.

Foothill yellow-legged frogs were found more often on streams with between 20 and 40 percent canopy cover, consisting of more than 40 percent riffle habitat and having at least 40 percent cobble substrate (Yarnell 2000). Kupferberg (1996) found that large boulders that did not move at stream discharges below bankfull, can slow and stabilize stream velocities. Boulders are important for safe basking locations and predator avoidance (Jennings 1988). In addition, foothill yellow-legged frogs typically occur on stream reaches with high width/depth ratios (low channel confinement), high meander/width ratios (high sinuosity), low to moderate gradients (<6.5 percent) and cross sectional configurations which include side channels (Kupferberg 1996b, Ibis Environmental Inc. 2002).

Yarnell (2000) found seasonal habitat preferences of different age classes were related to channel shape and streambed surface texture. Juveniles utilized swift, narrow channels during fall low flows, and then switched to wide, shallow channels with protected backwater areas during winter/spring high flow. Adults were usually found in confined channels with deep, narrow pools year round. Adults primarily occupied the deeper pools

with open canopies. In addition, Kupferberg (1996b) found the presence of foothill yellow-legged frogs was positively correlated with stream reaches within 400 m (0.25 mile) of tributary confluences. Adults used the tributaries for overwintering and the mainstem for breeding.

Movement and Dispersal

Diel and seasonal movements of foothill yellow-legged frogs and behavior of adults are poorly known (Jennings and Hayes 1994, Ibis Environmental, Inc. 2002). They do not leave riparian areas during storms, utilize moist open areas at night and are not seen on roads as are other ranids such as *Rana pipiens* or *Rana aurora* (Zweifel 1955). During the non-breeding season, home ranges appeared to be quite small in adult foothill yellow-legged frogs with average distances moved of 8 m (Van Wagner 1996). Morey (2000) suggested home ranges were probably less than 10 m. Breeding movement initiation temperatures are as low as 10°C (Drennan et al. 2006). Van Wagner (1996) reported average distance moved by adults during the breeding season was 54 m. Maximum distance travelled by females was 413 m and 408 m for males. These results suggest adults use a particular habitat for most of the year and move only in search of breeding areas. After the breeding season, adults may be scarce in ephemeral reaches of these breeding streams even in perennial pools, but are plentiful in tributaries (Van Wagner 1996). Alternatively, adults may move into vegetation or limit diurnal activity (Ashton 1998).

Young of the year and yearling frogs seem to move both upstream and downstream to areas with surface flow as streams dry back in summer and fall (Van Wagner 1996).

There was no significant difference in magnitude of movements of juveniles of both sexes between the breeding season and the remainder of the year (Van Wagner 1996). Juvenile movement was similar to adults during the breeding season, but was greater during the remainder of the year. Van Wagner (1996) reported maximum distances moved during the non-breeding season were 555 m for a juvenile and 25 m for an adult female. Van Wagner (1996) suggested juveniles move throughout the year in search of potential breeding habitat. There are no studies of tadpole dispersal distances.

Recent studies have revealed patterns in seasonal movements of adult foothill yellow-legged frogs. Wheeler and Welsh (2008) found that male frogs congregated at breeding areas during the breeding season, but females arrived asynchronously. On Red Bank Creek, a perennial tributary to the Trinity River in Tehama County, California, used 60 adult frogs for biotelemetry (Bourque 2005). Bourque found frogs seldom moved far from the wetted channel and movement patterns differed between the sexes. Long distance seasonal movements to and from breeding areas were confined to the spring breeding season. Another study tracked movements of 476 adult frogs on a regulated section of the North Fork Feather River (Drennan et al. 2006). They found adult frogs showed high site fidelity within tributaries to the mainstem of the river, which are home to adult frogs outside of the breeding season. Movements towards the breeding areas were triggered by day length. Males initiated movements first and left the breeding areas later than females. Females traveled at a much faster rate (up to 316.5 m/day) than males (up to 58.1 m/day). Adults started breeding in the mainstem once water temperatures were $\geq 10^{\circ}\text{C}$ and flows were ≤ 55 percent of baseflow on a descending limb of the

hydrograph. Female's length of stay was affected by flows and sex ratio. High flows and a lack of males delayed breeding and increased the amount of time females spent at the breeding sites. Males typically used breeding sites next to their home tributaries. However, some males utilized breeding locations near other tributaries.

Genetics

Genetics studies for foothill yellow-legged frogs are limited. Lind (2005) analyzed two fragments (Cytochrome B and ND2) of mitochondria DNA (mtDNA). These analyses showed there are several geographically supported clades within foothill yellow-legged frog that matched well with differences between clades in other taxa. The geographic breaks between clades fit with hydrologic regions that are likely to be poor dispersal corridors for foothill yellow-legged frogs. Genetic differentiation was low among populations within the largest clade. However, frogs in several localities showed significant divergence.

Another study analyzed both mtDNA and random amplified polymorphic DNA markers (Dever 2007). Dever sampled seven tributaries along the relatively pristine reach of the Eel River in northern California. The RAPD markers showed a positive correlation between genetic and geographic distance. Tributaries more than 10 kilometers (km) from each other exhibited little gene flow. The southern and northern tributaries were separated by cluster analysis. However, little geographic structure was found when the mtDNA was analyzed. Recent divergence, sex biased dispersal or the low number of loci used may explain this. The relatively pristine study area, with a lack of pollution, dams, roads and other manipulations, had a large population with a high level of genetic

diversity. A follow up study within this reach of the Eel River sampled nine tributaries and utilized three RAPD markers and sampled many more individual frogs (Poch and Dever 2008). They found high similarity among individuals of different tributaries, as evidence for significant genetic flow among the tributaries of the Eel River.

Predation

Foothill yellow-legged frogs are consumed by a wide variety of predators, including; birds, mammals, insects, reptiles and other amphibians (Duellman and Trueb 1986). The primary native predators throughout the range of foothill yellow-legged frogs are garter snakes (*Thamnophis spp.*). Western aquatic garter snakes (*Thamnophis couchi*) are known to take a heavy toll on all life stages (Nussbaum 1983, Jennings and Hayes 1988, Lind and Welsh 1994). Other species of garter snakes (*Thamnophis spp.*) prey primarily on postmetamorphic stages (Nussbaum 1983, Ashton et al. 1998). Rough skinned newts (*Taricha granulosa*) have been reported to feed on egg masses of foothill yellow-legged frogs in Southwestern Oregon (Evendon 1948). Foothill yellow-legged frog tadpoles are a component of Sacramento pike minnow (*Ptychocheilus grandis*) diet (Brown 1982). Egrets, herons and passerine birds have been known to consume tadpoles and post-metamorphic frogs of various anuran species (Duellman and Trueb 1986). American robins (*Turdus migratorius*) are highly skilled at capturing foothill yellow-legged frog metamorphs of, Pacific chorus frogs (*Pseudacris regilla*) and western toads (*Bufo boreas*) (pers. observ.). Raccoons (*Procyon lotor*) may opportunistically prey on foothill yellow-legged frogs (Zweifel 1955).

A principal non-native predator of foothill yellow-legged frogs is bullfrogs (*Rana catesbeiana*). Bullfrogs compete for the same resources as well as prey on native ranids throughout the west coast (Hayes and Jennings 1986, Jennings and Hayes 1988, Kupferberg 1996b). Bullfrog predation on foothill yellow-legged frogs was detected during a study on Cache Creek, a Clear Lake tributary, but extent of predation was indeterminable (Hothem et al. 2009). Introduced Centrarchids (basses and sunfishes) prey heavily on both egg masses and tadpoles (Hayes and Jennings 1986). Tadpoles are particularly vulnerable to small, fast maneuverable sunfish such as green sunfish (*Lepomis cyanellus*), because tadpoles have limited speed and stamina (Hayes and Jennings 1986). Signal crayfish (*Pacifasticus leniusculus*) were captured on video feeding on egg masses on the North Fork Feather River and may contribute to egg mass detachment (Jackman et al. 2004). In addition, visual inspections of tadpoles during VES suggest signal crayfish feed on tadpoles, based on tail injuries (Drennan et. al 2005). Introduced signal crayfish are present on many watersheds where foothill yellow-legged frogs reside. They may pose a serious threat, because foothill yellow-legged frogs lack evolutionary experience coping with crayfish predation.

Competition

A study by Kupferberg (1996a) implied that competition between foothill yellow-legged frogs, Pacific chorus frog, and bullfrog tadpoles results in 48 percent reduction in survivorship of foothill yellow-legged frog tadpoles and 16 percent reduction in size at metamorphosis. Tadpoles competed for algae directly in this experiment. Bullfrog tadpoles devoured most of the algae, due to their greater size. Bullfrog tadpoles do not

metamorphose in one year and consume algal resources year round (Kupferberg 1996b). The foothill yellow-legged frog co-exists with red-legged frogs on some streams, but competition is minimized by resource and habitat partitioning (Hayes and Jennings 1988).

Altered Streamflow Regimes

Anthropogenic flow alterations from impoundments are a great threat to foothill yellow-legged frog populations throughout their range. Impoundments may result in habitat fragmentation and reduced connectivity of metapopulations. Reduced summer streamflows may drive frogs into perennial pools and increase susceptibility to predation (Hayes and Jennings 1988). Habitat changes induced by altered flow regimes may create habitat preferred by bullfrogs, which are predators and competitors of foothill yellow-legged frogs (Hayes and Jennings 1988). Bullfrogs thrive in reservoirs and dredge ponds where water may be warm and of poor quality.

Wheeler and Welsh (2008) suggested anthropogenic manipulation of stream flows during the breeding season may suppress the reproductive behavior and output of egg masses. The magnitude and timing of spring pulsed flows from reservoirs greatly influence whether embryos survive long enough to hatch (Kupferberg et al. 2007). Smaller pulsed flows later in the breeding season may cause higher egg mortality than early season high magnitude pulsed flows, because jelly adhesion between eggs and cohesion to substrates are diminished in older egg masses. Effects of egg mass scour from pulsed flows may not be detectable for two or three years. A three year lag time between recruitment conditions and adult population size was observed based on

comparisons made between two reaches on the North Fork Feather River (Kupferberg et al. 2007). Further south, populations may have a two year lag time.

Impoundments may cause an artificial increase or decrease in water temperatures downstream (Catenazzi and Kupferberg 2009). Lower than natural summer releases most often result in unnaturally high stream temperatures. By contrast, cooler than normal water temperatures may result in releases from a reservoirs hypolimnion (cold bottom layer of a lake). Cooler releases can result in nearly doubling of the amount of time tadpoles take to complete metamorphosis and often results in smaller sizes than warmer temperatures. However, warmer temperatures were associated with outbreaks of the copepod *Lernaea cyprinacea* in foothill yellow-legged frogs in experimental enclosures (Catenazzi and Kupferberg 2009). Survival to metamorphosis was highest at intermediate temperatures.

An extensive effort by Garcia and Associates (2002) on the North Fork Feather River failed to find foothill yellow-legged frogs in habitats which appeared suitable for this species. The study areas were below impoundments operated by PG&E for hydroelectric power generation. A study on the Trinity River below Lewiston Dam, reported a 94 percent loss of potential breeding habitat after construction of the dam (Lind et al. 1996). Since Trinity River flows were controlled, there has been encroachment by riparian vegetation and reduced cobble/gravel bar formation. Flow releases had been reduced to 10–30 percent of pre-dam operation flows in both total volume and in periodic high flows (i.e. storm runoff) (Lind et al. 1996).

Egg masses have been scoured in several years by high late spring releases from Lewiston Dam (Lind et al. 1996). Ellis and Cook (2004) reported half of known egg masses were scoured by five days of high flow releases on the Pit River in California. They suggested duration of high flows and change in current direction (shearing) had a higher impact than overall magnitude. Jackman et al. (2004) also found pulsed flows scoured half of the egg masses on the North Fork Feather River, in only one day. Egg masses may be left to desiccate if receding high flows are poorly timed (Lind et al. 1996, Ashton 1998).

Laboratory and field experiments showed higher velocities caused short term behavioral responses on tadpoles (Kupferberg et al. 2007). Tadpoles would seek refuge within interstitial spaces of substrate. Velocities in which tadpoles could not swim or maintain position within substrate interstitial spaces varied with size, developmental stage and population origin. Long term consequences of tadpoles seeking high velocity refuge in substrates were increased risk of predation and reduced growth rates in larger tadpoles. Tadpole abundance dropped from the hundreds to a few at one site from a period of low flow to high flow and back to low flow during daily fluctuations for recreational whitewater rafting.

Recent hydraulic modeling studies have documented the effects of altered flows for foothill yellow-legged frogs. A study performed by Lind and Yarnell (2008), used depth, velocity and substrate as variables to develop a habitat suitability model/criteria for egg and tadpole stages of foothill yellow-legged frogs, which are the most susceptible to pulsed flows from hydropower generation or whitewater rafting recreation releases.

They found shallow, slow velocity waters with larger substrates had the highest suitability for egg and tadpoles. A study employing a two-dimensional hydrodynamic model using an un-regulated and regulated stream accurately predicted suitable breeding locations throughout these study reaches (Lind et al. 2009). Many pulsed flow scenarios were assessed to how habitat availability and suitability were affected. They found that lower discharges during spring provided the greatest weighted usable area for breeding. However, higher initial discharges resulted in egg laying in sites more resistant to later increases in velocity. Only 20 to 30 percent of suitable tadpole habitat on the un-regulated stream and <5 percent for the regulated stream was available during a summer pulsed flow, regardless of the initial flow. The observed differences in available habitat during the two pulsed flows between the un-regulated and regulated stream were likely because of differences in channel morphology.

Agrochemicals

Agrochemicals have been implicated in the decline of amphibians worldwide. Hayes et al. (2002) found hermaphroditism and other deformities in leopard frogs (*Rana pipiens*) exposed to commonly occurring levels of the widely used herbicide atrazine, both in the laboratory and in the field. Colborn and Clement (1992) attributed foothill yellow-legged frog population declines to endocrine mimicking chemicals that entered the ecosystem through pesticides and fungicides. Pesticide drift from the Central Valley to the Sierra Nevada and high pesticide levels in the bodies of Sierra Nevada amphibians have been well documented in California (Davidson et al. 2002). They found a strong positive association between declines of both California red-legged frogs (*Rana*

draytonii) and foothill yellow-legged frogs in areas downwind of agricultural land use. Fellers et al. (2007) exposed tadpoles for long periods of time in a laboratory to environmentally realistic concentrations of pesticides still in use. They concluded these pesticides are at sufficient concentration levels in the Sierra Nevada to cause a significant decrease in survival rates. Compounds from the breakdown of chlorpyrifos, malathion, and diazinon were found to be 10 to 100 times more toxic than the parent compounds (Sparling and Fellers 2007). Foothill yellow-legged frogs are far more susceptible to pesticides than Pacific chorus frogs (Fellers and Kleeman 2009). Chlorpyrifos was three times more toxic and Endosulfan was 40 times more toxic to foothill yellow-legged frogs.

Pathogenic Fungi

Pathogenic fungi have been documented to contribute to egg mass loss of several amphibians in the Pacific Northwest (Blaustein et al. 1994b). Amphibian declines in the US and Panama have been linked to the introduced fungus *Batrachochytrium dendrobatidis* (Bd), which causes chytridiomycosis (Fellers 2001). This disease causes abnormalities in jaw sheaths and teeth rows of tadpoles and is invariably fatal in populations of some species. An 11-year study on *Rana sierrae* and *Rana muscosa* revealed the extirpation of over 100 populations after the introduction of Bd since 1997 (Vredenburg et al. 2009). The disease spread at approximately 1 km a year in an easterly direction. Infections of frog populations reached 100 percent within weeks. All populations were stable prior to the onset of Bd invasion. Fellers (2001) sampled 25 counties in California and found chytridiomycosis in six species of amphibians

including foothill yellow-legged frogs in ten counties at 73 sites. Consequently, it appears chytridiomycosis affects a variety of taxon and is geographically widespread. Johnson and Saulino (2007), found Bd in all anuran species, including foothill yellow-legged frogs in and around Pinnacles National Monument and a few sites in the western foothills of the San Joaquin Valley. Lowe (2007) found 10 of 12 sites in the Diablo Range within San Benito and Fresno Counties were infected with Bd. However, the majority of postmetamorphic frogs were not infected. All foothill yellow-legged frogs >40 mm were chytrid free.

UV-B Radiation

A negative correlation was shown between hatching success and UV-B exposure in ranid species of the Pacific Northwest (Blaustein et al. 1994a). However, Davidson et al. (2002) found that patterns of amphibian declines in the Central Valley and Sierra Nevada in California were not consistent with the UV-B hypotheses.

MATERIALS AND METHODS

Study Area

The Coyote Creek watershed drains a portion of the central Diablo Mountain range in southeast Santa Clara County and flows into San Francisco Bay at Alviso Slough.

Anderson and Coyote Reservoirs impound runoff in the downstream end of the foothills portion of Coyote Creek. These reservoirs are operated for aquifer recharge in Santa Clara Valley by the Santa Clara Valley Water District. There are no significant impoundments upstream of Coyote Reservoir. Upstream of the reservoirs, the stream alternates between moderately confined channels and narrow alluvial valleys. Boulder, cobble and bedrock are the dominant substrates in the moderately confined sections, and cobble, gravel and boulder prevail in the channel within the alluvial valleys. Steeper tributaries enter in the alluvial valley reaches.

The study was conducted on upper Coyote Creek upstream of Coyote Reservoir from the inundation zone upstream to Gilroy Hot Springs (Figure 1).

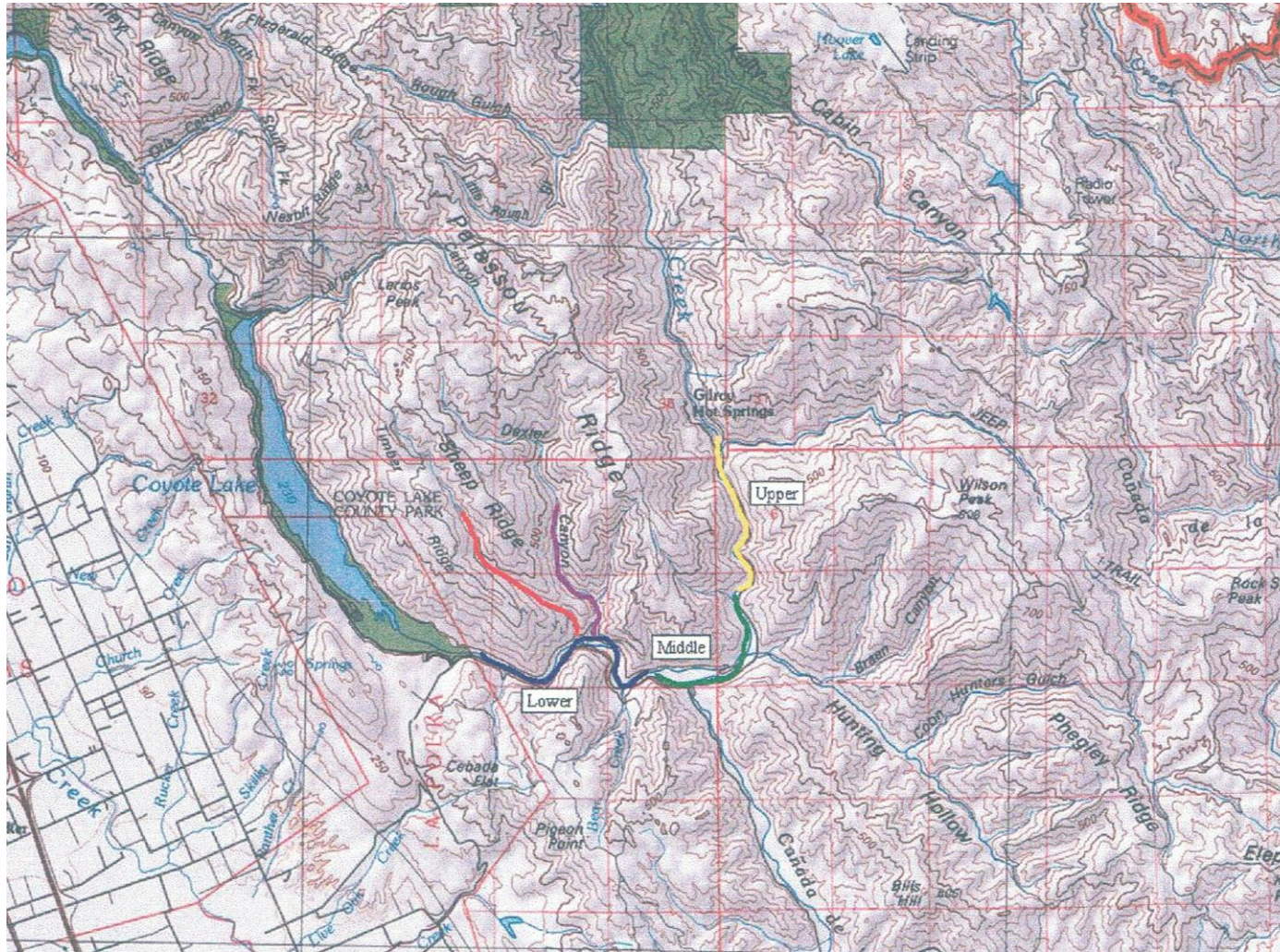


Figure 1. Map of study area. Data collection occurred on upper Coyote Creek between the high water mark of Coyote Reservoir and Gilroy Hot Springs.

The drainage area upstream of the study area encompasses over 176 square km (109 square miles). The study reach on the mainstem of Coyote Creek was approximately 7.8 km (4.83 miles) long. Also included were Dexter Creek 2.99 km (1.85 miles from confluence) and an unnamed tributary below Sheep Ridge 3.5 km (2.18 miles from confluence), which are tributaries containing foothill yellow-legged frogs. A small population of California red-legged frogs is sympatric with foothill yellow-legged frogs throughout the watershed upstream of Coyote reservoir.

The primary land use of the area adjacent to Coyote Creek upstream of Coyote Lake has been livestock grazing. The Santa Clara County Open Space Authority now owns and manages almost the entire study area. The upper 305 m (1,000 ft) of the study area is managed by California State Parks and is part of Henry Coe State Park, which contains the rest of the upper watershed. Livestock grazing is allowed on Open Space land, but is strictly managed to minimize effects on natural resources. No grazing is allowed on Henry Coe State Park, but occurred frequently near the park boundaries.

The upland plant communities adjacent to Coyote Creek and its tributaries are oak woodland, where moister, steep slopes adjoin the stream and grassland savanna on drier, flatter habitat. The oak woodland community is dominated by coastal live oaks (*Quercus agrifolia*) and California bay (*Umbellularia californica*). Other tree species include blue oak (*Quercus douglasii*), California buckeye (*Aesculus californica*) and foothill pine (*Pinus sabiniana*). Dominant riparian tree species along confined channels are white alder (*Alnus rhombifolia*), western sycamore (*Platanus racemosa*), willow (*Salix spp.*) and big leaf maple (*Acer marcophyllum*). The dominant trees in the grassland savanna

community are coastal live oak and California buckeye and a few valley oaks (*Quercus lobata*). The dominant riparian species in the alluvial reaches were western sycamore, scattered willows (*Salix spp.*) and mule fat (*Bacharis salicifolia*).

Habitat Mapping

I conducted mesohabitat mapping during spring 2004 as high flows subsided and oviposition had ceased. Mesohabitats were identified as pool, riffle or run (Hawkins et al. 1993). I used flagging to identify all mesohabitats. I labeled flagging with habitat unit numbers and identified bottom or top of habitat units with distances in meters from the bottom of the study reach. I added additional flagging within large habitat units with distances in meters from the bottom of the respective unit, to facilitate pinpointing future frog capture/recapture locations. I collected physical mesohabitat data that included: mean depth, maximum depth and mean width, which were measured in feet with a stadia rod. I measured mesohabitat lengths with a surveyor's hip chain. I determined Rosgen channel geomorphology types by measuring width to depth ratios of the bankfull channel (i.e. channel confinement), the ratio of low flow channel width to bankfull depth (i.e. entrenchment) and channel gradient (Rosgen, 1996).

I collected data on habitat parameters for the purpose of determining if these were good predictors of abundances of adult foothill yellow-legged frogs. I identified and recorded instream cover types for each habitat. Cover types included: woody debris, undercut bank, boulder/cobble, bedrock, terrestrial vegetation, depths and water surface turbulence. I measured the percentage riparian canopy closure using a spherical

densitometer. I visually estimated substrate types for each mesohabitat to the nearest 10 percent. Substrate types included: silt/clay, sand, gravel (5–75 mm), cobble (75–300 mm) boulder (>300 mm), and bedrock. In addition, I recorded other aquatic species observed in each mesohabitat. I minimized potential impacts to foothill yellow-legged frog egg masses by identifying oviposition locations prior to mapping. In addition, I removed hip chain string as I proceeded.

Visual Encounter Surveys

From 14 March 2004, to 16 November 2005, 14 March and 23 March to 10 April 2006, I conducted VES at least weekly for the entire study area, where suitable habitat (i.e. water) existed for the duration of the study using the same USDA-FS protocols as *Standard Operating Procedures for River and Creek Visual Encounter Surveys* (Bury and Corn 1991). In addition, I conducted some night surveys on a monthly basis through all suitable habitats. I conducted a total of 215 VES, and all sites were checked at least sixty times. I used binoculars to scout open and exposed areas for frogs (Seltenrich and Pool 2002). I proceeded slowly upstream, zigzagging from one bank to the other searching the banks and channel for egg masses, tadpoles, metamorphs and adult foothill yellow-legged frogs. I used a dipnet to flush frogs from bank vegetation and sweep undercut banks and emergent vegetation. I bypassed dry areas and proceeded to the next suitable habitat. I exercised caution to avoid stirring up sediment or dislodging egg masses of all stream breeding amphibians.

I attempted to capture all frogs with a dipnet or by hand. Age class (adult, subadult, metamorph), sex (Stebbins 2003) and SVL were determined and recorded before releasing frogs at location of capture. I recorded captured and observed frogs to the specific mesohabitat (habitat unit number) and measured distance from exact positions within it from the top or bottom of the habitat. I characterized and recorded microhabitats utilized by frogs as; isolated pool, connected side pool, scour pool, backwater pool, sidechannel, boulder-sedge, edgewater, pool tailout, riffle, exposed bank, protected bank or cobble/gravel bar (Seltenrich and Pool 2002, PacifiCorp 2002). In addition, I recorded activities of captured and observed frogs as; sitting in shade, basking, hiding under substrate, calling, swimming, foraging, amplexus, floating or underwater (on bottom). I hung flags as close to the capture or location of observation as possible to monitor any changes in distribution of recaptured frogs within or between mesohabitats (Ibis Environmental Services 2002).

I surveyed for egg masses from early March to the end of the breeding season in both 2004 and 2005. I determined specific mesohabitats used (habitat unit number) and exact locations (distance from top or bottom of the habitat) of egg mass or clusters of egg masses. I determined egg mass diameter (mm), attached substrate diameter (mm) and shape (angular or rounded), distance from shore, depth at egg mass attachment point and disposition of egg mass (intact, damaged, hatching, hatched). I estimated numbers of tadpoles for each mesohabitat during each VES. I determined and recorded the same in-channel microhabitat characteristics for tadpoles as for the adults and subadults.

Mark and Recapture

I conducted mark and recapture of frogs simultaneously with VES. I marked 121 adult (>40 mm SVL) and 61 juvenile frogs (young of the year and yearling) for mark and recapture to determine movement patterns from 18 July 2004, to 16 November 2005. Seventy-two frogs were marked in 2004. These consisted of 32 adults (18 females and 14 males) and 40 juveniles (mostly young of the year). One hundred ten frogs were marked in 2005. These consisted of 89 adults and 21 juveniles. I marked frogs with soft, three digit numeric, color coded vi-alpha tags (Northwest Technologies, Inc.) which were injected subcutaneously in the dorsal thigh (Chelgren 2003). I massaged the tags to the ventral side of the thigh to avoid tag loss through the incision and to allow for tags to be viewed through transparent skin (Chelgren 2003). I manually restrained captured frogs and kept the legs and arms stationary. I recorded SVL and sex prior to release at exact location of capture. In addition, I determined and recorded the same meso and microhabitat data as the VES.

Radiotelemetry

I attached radio transmitters (Holohil Systems Ltd.; BD-2 transmitters) weighing (0.90–1.20 grams [g]) to five large adult foothill yellow-legged frogs weighing at least 15 g (Mathews and Pope 1999, Watson et al. 2003) between early June 2005 and mid October 2005, after breeding frogs regained and stabilized their weight. Initially, my goal was to fit transmitters to frogs in late winter before breeding and track them to the breeding area. However, heavy rains and high flows prevented me from achieving this in

2005. I used a custom fitted bead chain (key chain) to attach transmitters (Mathews and Pope 1999; Ritson and Hayes 2000; Goldberg et al. 2002). The combined weight of the transmitter was 1.5 g to satisfy the ten percent rule of transmitter to body weight to minimize the effects of the transmitter on the frogs (Mathews and Pope 1999; Watson et al. 2003).

I captured five frogs (three females >30 g and two males >20 g) to be fitted with radio transmitters by hand or dipnet and restrained them using the same protocol as frogs marked with vi alpha tags. Frogs were released 24 hours after attachment of radio transmitters to the exact location of initial capture. I recorded the same meso and microhabitat data as vi alpha marked frogs, determined sex and measured SVL. Frogs were tracked simultaneously with VES. I tracked frogs at least twice weekly using a tectonics receiver with a hand held H-flex antenna (Ritson and Hayes 2000). I recovered the radio transmitter apparatus from all frogs between mid-October 2005 and 16, November 2005. Battery life of these transmitters was 16 to 20 weeks. I determined distances traveled from the last location by noting the exact mesohabitat with predetermined distances in feet from a known landmark and measured locations from the top or bottom of the habitat. Tracked frogs were located twice daily, first in the morning and later relocated in the late afternoon.

Streamflow Discharge

Daily and hourly streamflow data were retrieved from U.S. Geological Survey (USGS) Station Number 111698800 on Coyote Creek upstream of Coyote Reservoir and

Downstream of Henry Coe State Park. The gauge is about midway through the downstream reach about 60 ft downstream of the confluence of Dexter Creek and the mainstem of Coyote Creek. This station was inoperable during 2004. As a consequence, I used data from a nearby watershed (Lower Llagas Creek) within the Gilroy city limits. I retrieved these data from USGS station number 1153650 to determine storm runoff.

Temperature

Stream temperatures were recorded daily at one hour intervals from January 2005 to fall 2005, using Optic Stowaway temperature loggers in degrees Celsius (°C). Loggers were housed in steel plumbing joints and chained to objects unlikely to move at high flows. I installed loggers at four locations within the study area. Two locations were at the upper and lower ends of the study area and two were located nearly evenly spaced in between. In addition, temperature loggers were installed in perennial pools on Dexter Creek and on an unnamed tributary below Sheep Ridge. Both tributaries were occupied by adult foothill yellow-legged frogs throughout the year. I used a hand thermometer to take spot temperatures during the initiation of breeding in 2004 and 2006. I did not have access to temperature loggers during 2004 and 2006.

Analyses

I ran ANOVA and unpaired two sample t-tests for a comparison between 2004 and 2005 for depth of egg mass deposition, distance from shore of spawning and attachment substrate sizes.

MYSTAT 12, a student version of SYSTAT 12 was used to test assumptions of equal variances and sample means. Comparisons of average maximum distances traveled by season were made between all frogs, all adults, adult males versus females and adults versus juveniles. Unpaired two-tailed t-tests were employed in instances in which the null hypothesis was accepted for equal variances. The Wilcoxon test for equal sample means was used in one instance where the null hypothesis for equal variances was rejected (adults vs. juveniles). The Von Bertalanffy Growth Equation (VBGE) was used to produce predictive growth curves for small (17 mm) and large (22 mm) metamorphs and compared with frogs sampled on the Feather River during 2004. I performed chi squared tests for goodness of fit for mesohabitat as well as mesohabitat substrate dominance use/preference of adult foothill yellow-legged frogs from the cessation of breeding to the summer drybacks. I used both t-tests and non-parametric tests of significance for adult foothill yellow-legged frog mean maximum depths, mean canopy and mean number of cover types (cover complexity).

RESULTS

General Breeding Pattern

The lower and upper breeding sites (upper and lower reaches) were separated from one another by 4 km (2.5 miles) of the middle reach (Figure 1), where no breeding was detected in 2004 and 2005. A total of 72 egg masses were deposited for the two sites during 2004, with a combined density of 0.0149 mass/km (Table 1).

Table 1. 2004 and 2005 Spawning season summary on Coyote Creek Upstream of Coyote Reservoir in Santa Clara County, CA.

	Start Date of Breeding	Finish Date of Breeding	Breeding Season Length (Days)	Total Egg Mass Number	Egg Mass Density (mass/m)
2004					
Lower Reach	3/7/2004	3/31/2004	24	41	0.0172
Upper Reach	3/24/2004	4/20/2004	27	31	0.0126
Total	n/a	n/a	44	73	0.0149
2005					
Lower Reach	3/12/2005	5/14/2005	63	59	0.0248
Upper Reach	4/4/2005	5/16/2005	42	44	0.0179
Total	n/a	n/a	65	103	0.0214

Breeding increased at both sites in 2005, with 103 egg masses deposited, with a density of 0.0214 mass/km. Breeding started slightly later and lasted much longer at both sites during the wetter 2005. Breeding started at the lower reach three days earlier in 2006 than in 2005 and two days later than 2004. However, hatching success decreased on the lower reach from 100 percent in 2004 to 73 percent in 2005 (Table 2).

Table 2. Hatching success of egg masses on Coyote Creek 2004–2005.

	Number of Egg Masses	Scoured/Missing	Hatching Success	Mean Number of Days to Hatch	Range
2004					
Lower Reach	41	0	100%	13	10-14
Upper Reach	31	0	100%	no data	no data
Total	72	0	100%		
2005					
Lower Reach	59	16	73%	12	6-26
Upper Reach	44	0	100%	14	8-19
Total	103	16	85%		

This was due to scour of masses from a particularly intense storm during late March. Egg mass survival at the upper reach was 100 percent in both years. The mean number of days for eggs to hatch was similar on the lower reach between 2004 (mean = 13) and 2005 (mean = 12), but the range in 2005, with the longer breeding season, was much higher (6-26 days versus 10-14 days). The mean number of days to hatching on the upper reach in 2005 was slightly higher than at the lower reach (14 versus 12) and the range was narrower (8-19 versus 6-26).

Average egg mass diameter was smaller in 2005 on both reaches. Egg masses became smaller as the breeding season progressed, and the effect was more pronounced during 2005 than during 2004 on the upper reach (Figures 2 and 3).

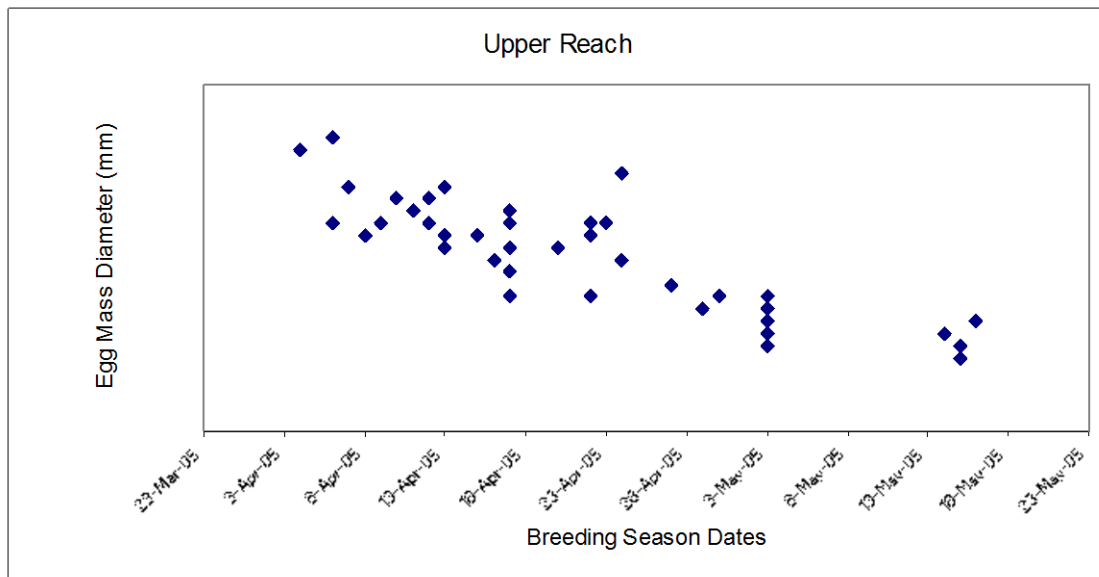
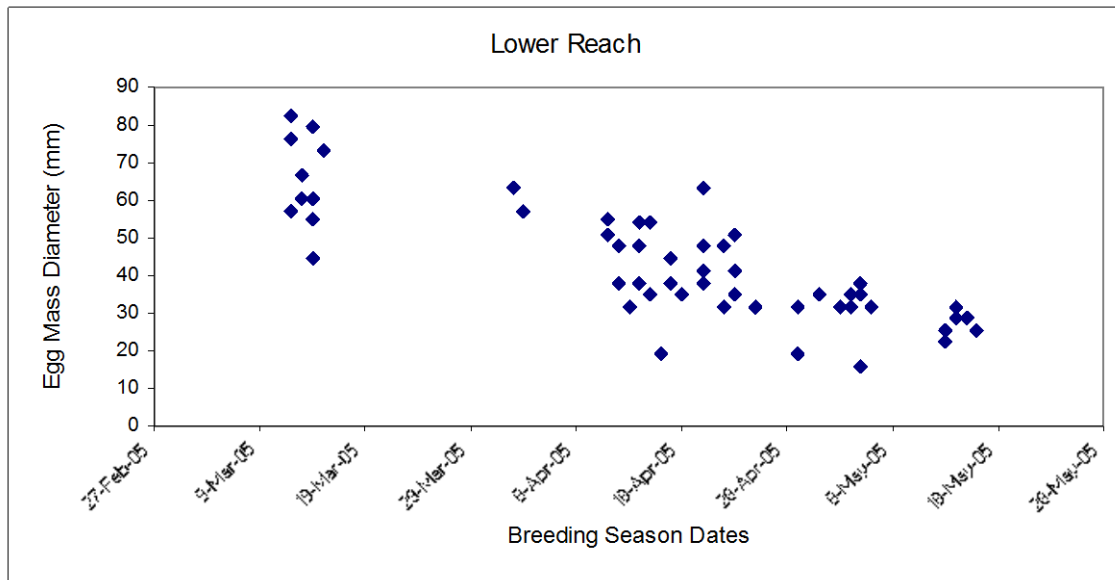


Figure 3. Egg mass diameter through the breeding season on the upper reach of Coyote Creek in 2005.

2005 mean clutch sizes for both reaches combined were 60 mm during the first third of the breeding season, 43 mm during midseason and 29 mm during the last third of the

season. A three way ANOVA showed these differences between early, mid and late season clutch sizes to be significant using Levene's Test ($df = 2, 100$, $\alpha = 0.025$, critical $F = 3.83$, calculated $F = 4.871$).

The mean depth at which eggs were deposited was significantly deeper during 2005 (0.237 m) than in 2004 (0.157 m) (unpaired two sample t-test, $\alpha = 0.025$, $df = 173$, critical $t = 1.974$ and calculated $t = -3.056$). Egg deposition was closer to the edge of the wetted channel in 2005 (2.201 m) than 2004 (2.636 m). However, the distance was not significantly different because of wide variation in both years (unpaired two sample t-test, $\alpha = 0.025$, $df = 173$, critical $t = 1.974$ and calculated $t = 2.166$). Egg attachment substrates were significantly larger during 2005 (68 mm) than 2004 (59 mm) (unpaired two sample t-test, $\alpha = 0.025$, $df = 165$, critical $t = 1.974$ and calculated $t = -0.455$).

Streamflow and Breeding

Breeding initiation occurred within a week after the last significant storm on both reaches in 2004 (Figures 4 and 5).

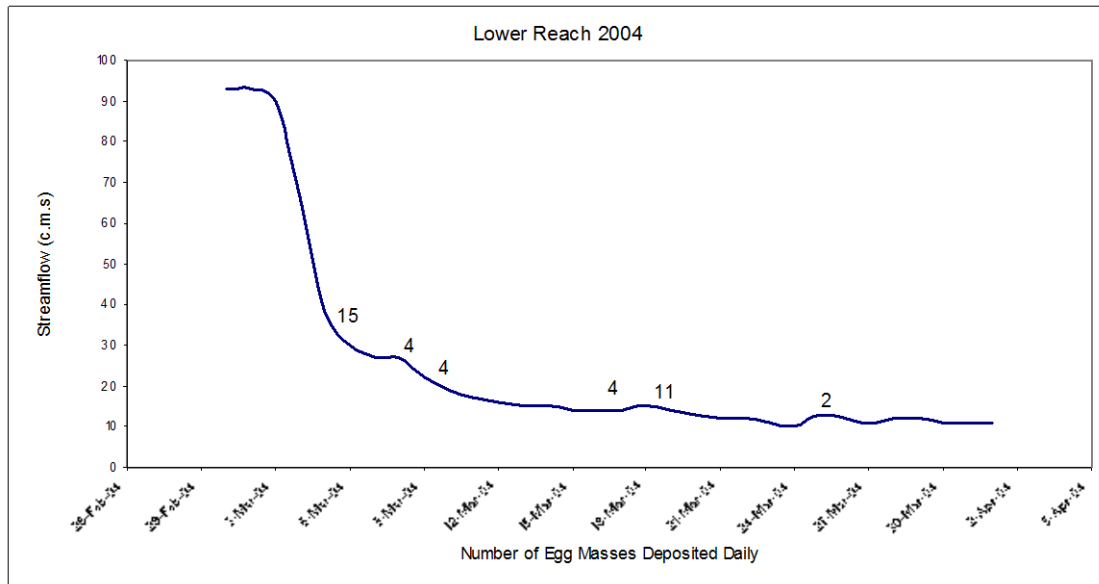


Figure 4. Streamflow in association with daily oviposition on the lower reach of Coyote Creek in 2004.

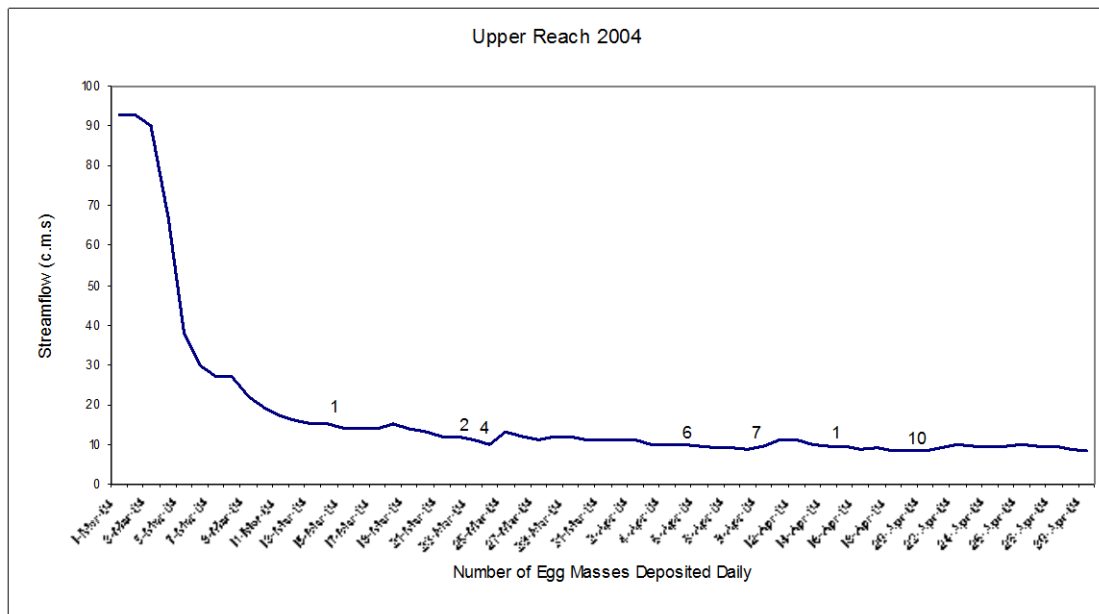


Figure 5. Streamflow in association with daily oviposition on the upper reach of Coyote Creek in 2004.

All egg masses were deposited on the descending limb of the hydrograph generated by the last storm. Stable spring base flows (approximately 2.44 cms or 8 cfs) were reached by early April 2004. By contrast, stable spring base flows were not reached until late May in 2005 (Figures 6 and 7).

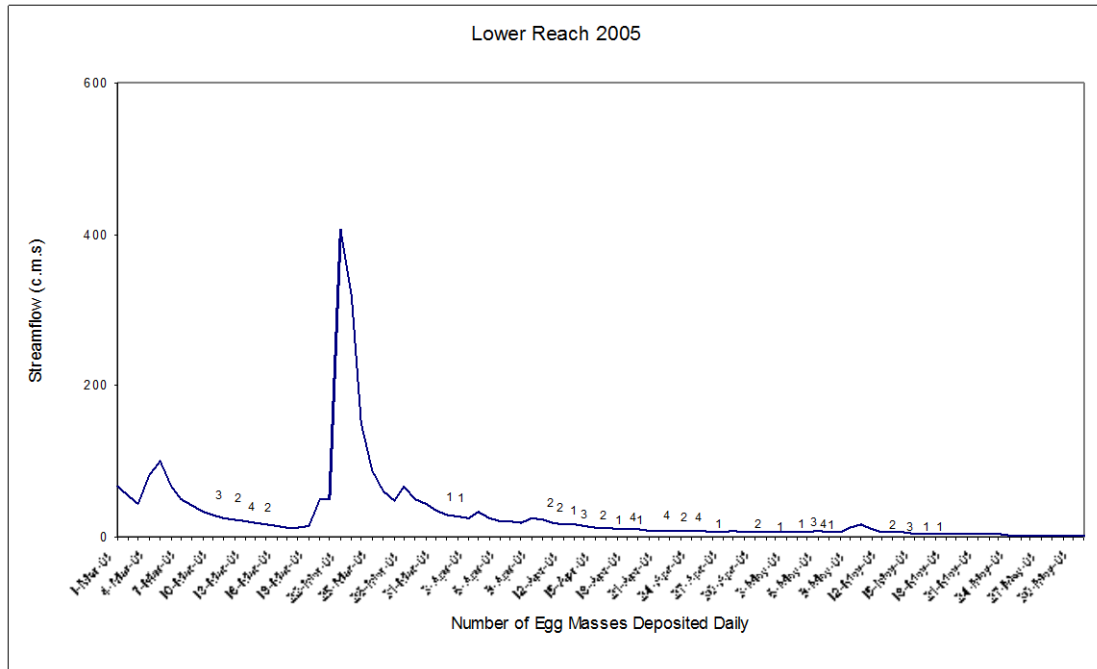


Figure 6. Streamflow in association with daily oviposition on the lower reach of Coyote Creek in 2005.

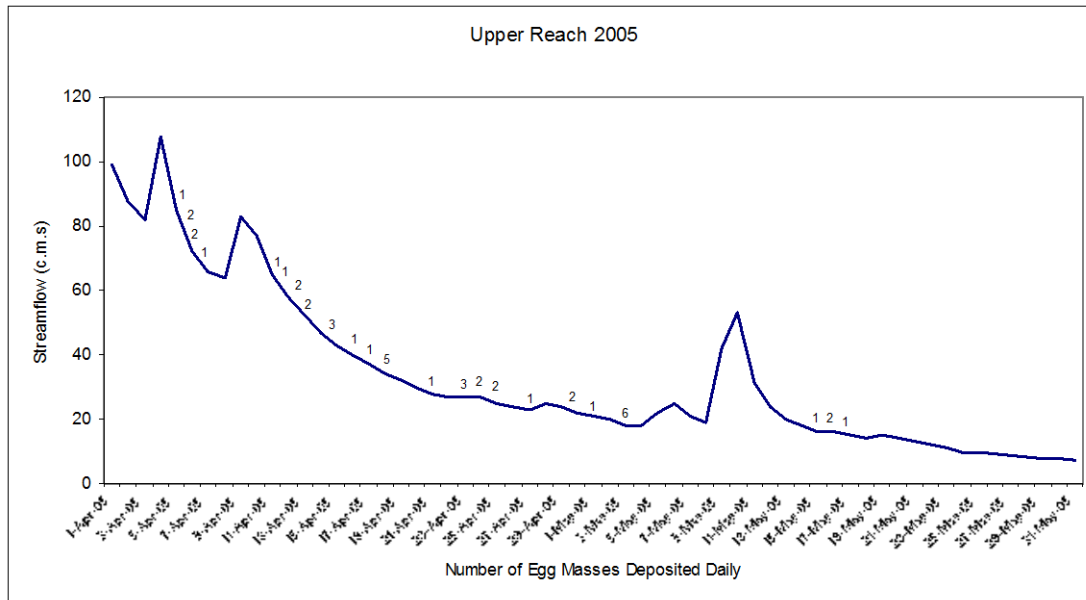


Figure 7. Streamflow in association with daily oviposition on the upper reach of Coyote Creek in 2005.

Stream flows varied between 4.88-4.5 cms (16-1,330 cfs) during the breeding season in 2005. However, the highest mean daily discharge recorded during a day that breeding occurred was 23.5 cms (77 cfs). Breeding initiation in 2005 occurred within a week by calendar date compared with 2004, despite the drastically different flows between the two years. Nine of eleven early egg masses deposited at the lower site during 2005 were scoured by consecutive large storms that lasted about ten days in March. Flows increased three more times during the breeding season, due to moderate sized storms that persisted into early May. All egg masses on both reaches were deposited on descending limbs of the hydrograph during 2005. No egg masses were deposited within the upper reach prior to the large storms in late March.

Temperature and Breeding

No temperature data were collected to calculate daily mean, minimum and maximums during the 2004 breeding season. However, hand thermometer readings were recorded when new egg masses were encountered and temperatures were always greater than 12°C. The lowest daily mean water temperature recorded on a day when breeding occurred was 11.3°C during on 4 April 2005 on the upper reach. Mean daily temperatures exceeded 12°C on the lower reach by March 1 March 2005. However, breeding was not initiated until 12 March 2005. The majority of egg masses (72 of 103) were deposited during days when daily mean water temperatures ranged between 13 and 17°C on both reaches (Figures 8 and 9).

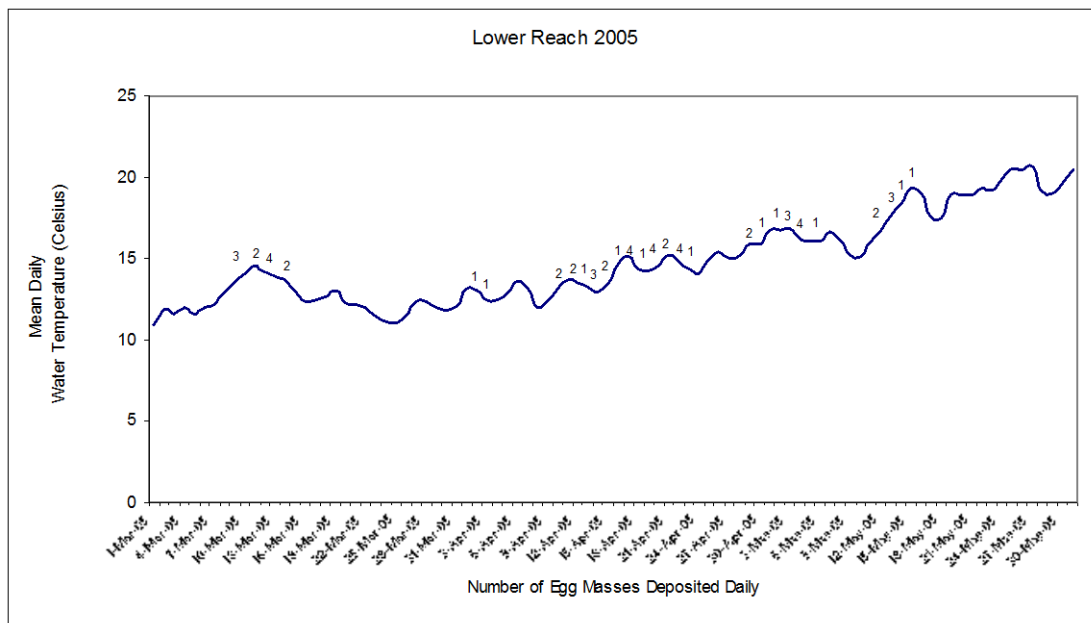


Figure 8. Water Temperature in association with daily oviposition on the lower reach of Coyote Creek in 2005.

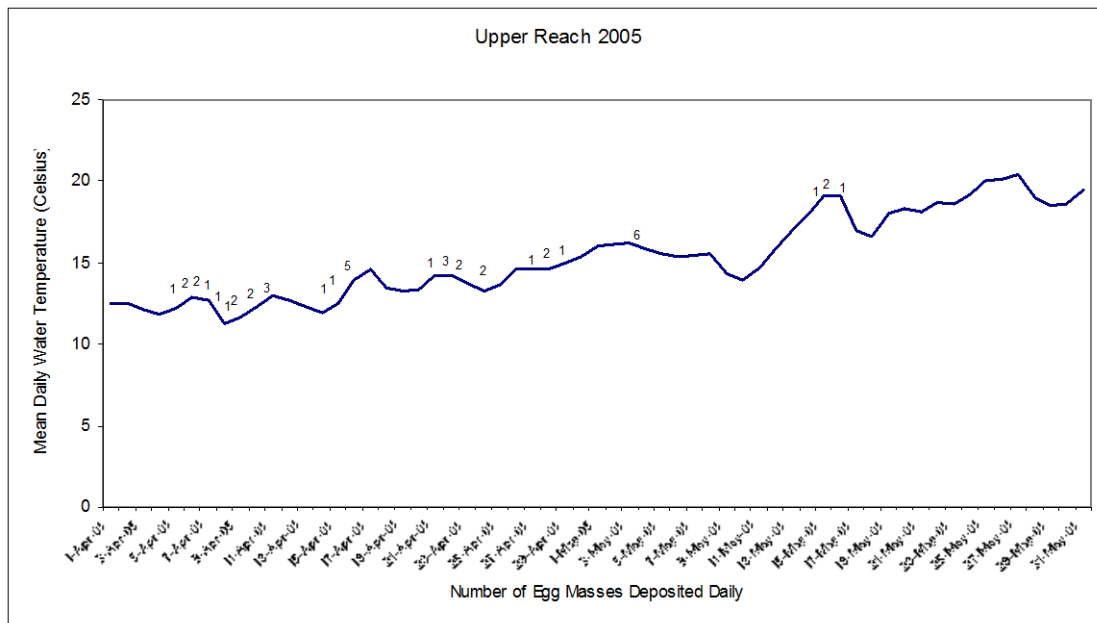


Figure 9. Water Temperature in association with daily oviposition on the upper reach of Coyote Creek in 2005.

This includes egg masses deposited during the first half of March on the lower reach. No breeding occurred on during days with daily mean temperatures exceeding 19.3°C.

Physical and Habitat Parameters for Egg Masses

Lower Reach

Breeding took place within seven pool habitats and one run during 2004 on the lower reach (Table 3).

Table 3. Mesohabitat use percentages for 176 foothill yellow-legged frog egg masses ovideposited within the study area on Coyote Creek during 2004–2005.

	Proportion of Egg Masses in Pools	Proportion of Egg Masses in Flatwater	Number of Mesohabitats Utilized	Percentage of same Mesohabitats used in 2005 from 2004
2004				
Lower Reach	97.5%	2.5%	8	n/a
Upper Reach	100%	0%	8	n/a
2005				
Lower Reach	95%	5%	9	70%
Upper Reach	100%	100%	8	60%

Two different pools were utilized for breeding in 2005. The new pools used in 2005 were downstream of and adjacent to the downstream most pool used in 2004. All meso-habitats utilized for breeding during both years held water at least until August and are either perennial meso-habitats or are adjacent to one. All meso-habitats on the mainstem that held water at least until August were used for breeding. About half (54 of 99) the egg masses during both years were deposited near the tail of breeding pools and most of the rest (41 of 45) were near the middle (Table 4).

Table 4. Microhabitat parameters for egg masses deposited within the study area on Coyote Creek 2004–2005.

Position in Pool	Head	Middle	Tail			
2004						
Lower Reach	5%	40%	55%			
Upper Reach	0%	23%	77%			
2005						
Lower Reach	4%	43%	53%			
Upper Reach	2%	75%	23%			
Microhabitat	Submerged	Submerged	Edgewater	Glide	Deep	Thalweg
	Gravel Bar	Cobble Bar			Water	
2004						
Lower Reach	76%	2%	22%	0%	0%	0%
Upper Reach	81%	19%	0%	0%	0%	0%
2005						
Lower Reach	53%	20%	24%	3%	0%	0%
Upper Reach	70%	0%	0%	23%	5%	2%

All egg masses during 2004 were attached to stones. However, five egg masses were attached to vegetation or roots in 2005. The majority (76 and 69 percent) of egg masses during both years were deposited on gravel (5–75 mm) substrates. There was an increase in the use of cobble for attachment during 2005 (22–29 percent). Submerged gravel bars

were the most frequently chosen areas of pools during both years, but there was a significant increase in use of cobble bars during 2005 (Table 5).

Table 5. Attachment substrate of egg masses on Coyote Creek 2004-2005.

	Stone (%)	Vegetation/Roots (%)	Mean Diameter of Stone (mm)
Lower Reach			
2004	100	0	73
2005	92	8	71
Upper Reach			
2004	100	0	43
2005	100	0	52

Oviposition occurred in deeper water and somewhat closer to shore in 2005, but egg masses had lower canopy closure in 2004 than 2005 (27 and 31 percent) (Table 6).

Table 6. Spawning habitat parameters measured at egg mass locations along Coyote Creek 2004-2005.

	Mean/Total (n)	SE	Range
Lower Reach 2004			
Distance from shore (m)	2.23 (41)	0.212	0.610-6.08
Water Temperature (°C)	no data	no data	no data
Canopy coverage (%)	27% (41)	3.666	2%-96%
Egg mass diameter (mm)	57 (5)	5.418	38-70
Water depth at egg mass (m)	0.131 (41)	0.009	0.60-0.320
Lower Reach 2005			
Distance from shore (m)	1.91 (59)	0.178	0.100-6.52
Water Temperature (°C)	14.9 (59)	0.215	12.5-19.3
Canopy coverage (%)	31% (59)	3.011	2%-96%
Egg mass diameter (mm)	43 (59)	2.046	16-83
Water depth at egg mass (m)	0.237 (59)	0.027	0.06-1.14
Upper Reach 2004			
Distance from shore (m)	3.178 (31)	0.16	0.78-4.53
Water Temperature (°C)	no data	no data	no data
Canopy coverage (%)	32% (31)	3.586	5%-85%
Egg mass diameter (mm)	51.4 (29)	2.441	38-79
Water depth at egg mass (m)	0.191 (31)	0.013	0.08-0.46

Table 6. Spawning habitat parameters measured at egg mass locations along Coyote Creek 2004-2005 (continued).

	Mean/Total (n)	SE	Range
<u>Upper Reach 2005</u>			
Distance from shore (m)	2.59 (44)	0.182	0.27-5.61
Water Temperature (°C)	14.3 (44)	0.297	11.3-19.1
Canopy coverage (%)	18% (44)	1.41	6%-48%
Egg mass diameter (mm)	46 (44)	2.196	19-76
Water depth at egg mass (m)	0.238 (44)	0.035	0.10-1.66

Upper Reach

Breeding took place in eight pool habitats during both years on the upper reach (Table 3), but three pools were different between years. The new pools used in 2005 were adjacent to the pools used in 2004. Over three quarters (24 of 31) of the egg masses in 2004 were deposited near the tail of breeding pools (Table 4). In contrast, frogs chose the middle of pools over the tailouts for oviposition (33 of 44) during 2005. All egg masses during both years were attached to stones (Table 5). The majority (65 of 75) of egg masses during both years were deposited on gravel substrates. There was an increase in the use of cobble (from 7 to 18 percent) for attachment during 2005. Submerged gravel bars were the most frequently chosen areas of pools during both years. However, frogs used deeper slack water during 2005. Oviposition occurred in deeper water (0.191 m versus 0.238 m) and somewhat closer from shore (3.178 m versus 2.59 m) and at locations with more open canopies in 2005 in comparison to 2004 (18 versus 32 percent) (Table 6).

Movement/Mark/Recapture

General Characteristics

A total of 182 frogs were marked during 2004–2005. This included 106 males, 67 females and eight undeterminable frogs. A total of 106 frogs were recaptured at least once and 65 individual frogs were recaptured at least twice. Male to female sex ratios ranged from 1.29 to 2.13, for frogs recaptured four or less times (Table 7).

Table 7. Capture counts for marked frogs during 2004–2005 on Coyote Creek and associated tributaries.

Number of times captured	Total number of individuals	Number of males	Number of females	Number of undetermined	Male to female ratio
1	182	106	67	8	1.58
2	41	22	17	2	1.29
3	25	17	8	0	2.13
4	18	11	7	0	1.57
5	8	5	3	0	1.66
6	3	1	2	0	0.5
7	2	1	1	0	1
8	0	0	0	0	n/a
9	0	0	0	0	n/a
10	0	0	0	0	n/a
11	1	1	0	0	n/a
12	0	0	0	0	n/a
13	0	0	0	0	n/a
14	0	0	0	0	n/a
15	0	0	0	0	n/a
16	0	0	0	0	n/a
17	0	0	0	0	n/a
18	1	0	1	0	n/a
19	0	0	0	0	n/a
20+	*7	3	4	0	0.75

*Three females and two males were radiotagged frogs

The observed male to female sex ratio during the 2005 breeding season was 1.48 on the lower reach and 1.85 on the upper reach. A total of 58 juvenile frogs were marked during 2004–2005. All juveniles marked during 2004 were young of the year and yearling frogs

during 2005. Yearling frogs marked during 2005 were 2004 cohort frogs that overwintered. Four female and six male juveniles were recaptured as adults (Table 8).

Table 8. Juvenile mark and recapture summary from 2004 to 2005.

	Number Marked	Recaptured Once (%)	Recaptured Two or More Times (%)	Number Recaptured as Adults	
				Females	Males
2004					
Lower	14	29	14	2	1
Middle	0	0	0	0	0
Upper	25	32	12	0	3
Dexter Creek	0	0	0	0	0
Sheep Ridge Creek	0	0	0	0	0
Total	39	31	13	2	1
2005					
Lower	11	73	36	1	3
Middle	0	0	0	0	0
Upper	2	100	50	0	2
Dexter Creek	4	75	50	1	0
Sheep Ridge Creek	2	50	0	0	0
Total	19	74	37	2	5

Snout to urostyle length (mm) and weight (g) ranges for both adult males and females were very similar between 2004 and 2005. Maximum weights of females were nearly twice that of males throughout the study area during both years (Table 9).

Table 9. Size ranges of adult foothill yellow-legged frogs captured within the study area during 2004-2005.

	Females			Males		
2004	N	Weight (g)	SVL (mm)	N	Weight (g)	SVL (mm)
Lower	1	7.5	42	2	9.8-11.0	41-47
Middle	1	7.5	40	0	n/a	n/a
Upper	9	9.0-37.0	45-71	11	6.5-16.3	40-55
Dexter Creek	7	11.2-45.0	41-72	1	20.5	57
Sheep Ridge Creek	0	n/a	n/a	0	n/a	n/a
Total	18	7.5-45.0	40-72	14	6.5-20.5	40-57

Table 9. Size ranges of adult foothill yellow-legged frogs captured within the study area during 2004-2005 (continued).

2005	Females			Males		
	N	Weight (g)	SVL (mm)	N	Weight (g)	SVL (mm)
Lower	4	7.5-43.5	41-71	20	8.0-26.0	40-58
Middle	0	n/a	n/a	0	n/a	n/a
Upper	7	8.5-32.5	42-63	9	8.5-18.0	41-54
Dexter Creek	20	7.5-48	40-74	25	9.0-25.0	41-59
Sheep Ridge Creek	2	11.0-28.5	46-57	1	8.5	42
Total	33	7.5-48.0	40-74	55	8.0-26.0	41-59

Most lower reach adult females resided on Dexter Creek outside of the breeding season during both 2004 and 2005. Nearly two thirds of lower reach adult males captured during 2005 resided on Dexter Creek. However, only one third resided on Dexter Creek during 2004 (Table 10).

Table 10. Residence locations and numbers of female and male frogs captured at the breeding locations.

Residence locations for adults		
	Mainstem (Lower Reach) (n) %	Dexter Creek (n) %
Males		
2004	(2) 66%	(1) 33%
2005	(16) 36%	(26) 64%
Females		
2004	(1) 13%	(7) 87%
2005	(3) 13%	(20) 87%
Adult frogs captured at or near the lower and upper breeding sites during 2005		
	Lower Reach	Upper Reach
Males	40	13
Females	27	7
Ratio (males/females)	1.48	1.85

The number of frogs observed and captured on the lower reach breeding site started to increase as temperatures reached about 10°C in mid-February and peaked starting in mid-

march through mid-May 2005. This coincided with rising water temperatures, particularly when 12°C was reached and surpassed.

Observations of adult frogs on the lower reach sharply declined soon after spawning ceased in mid-May (Figure 10).

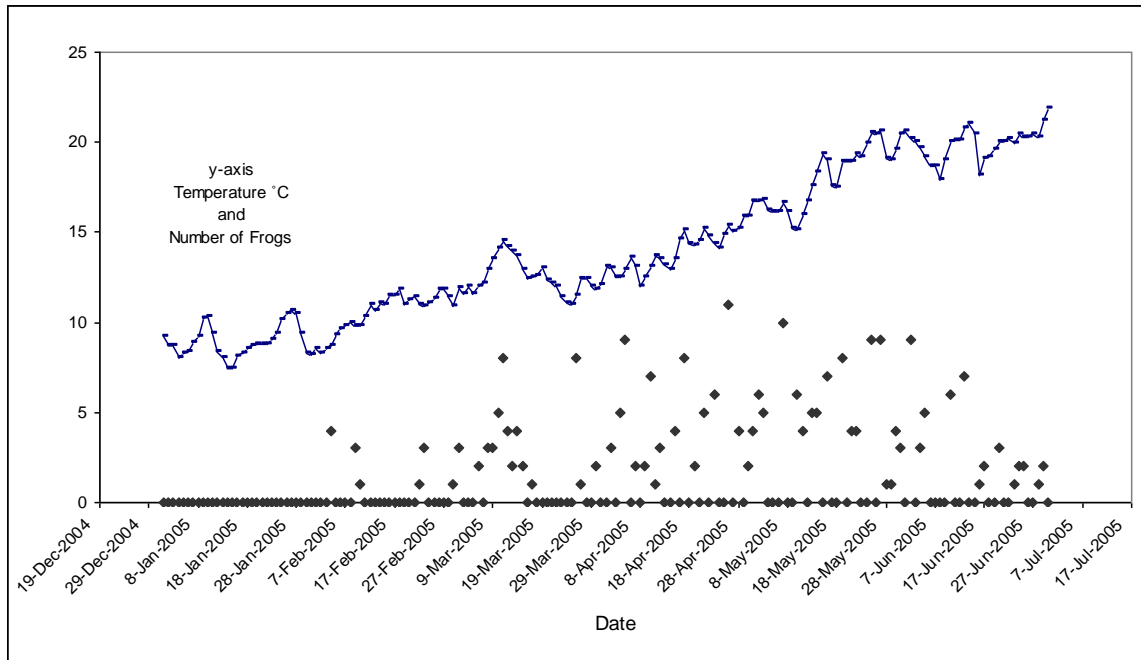


Figure 10. Number of frogs observed during surveys and recorded daily mean water temperatures during the pre-spawning/spawning season in 2005.

The number of males observed outnumbered that of females the majority of the time, especially prior to and after active breeding occurred (Figure 11).

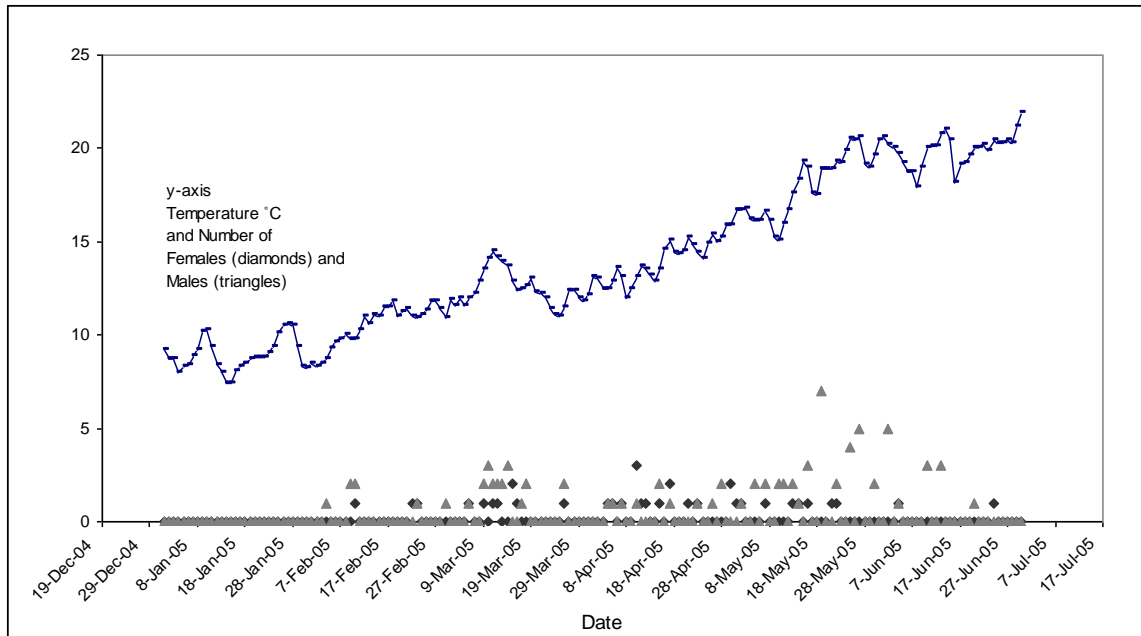


Figure 11. Number of female and male frogs observed during surveys and recorded mean daily water temperatures during the pre-spawning/spawning season in 2005.

The upper reach has a tributary (Long Canyon Creek) with resident foothill yellow-legged frogs. These frogs are highly likely to breed on the upper reach and make significant movements to and from the mainstem. I did not include this tributary as part of my visual encounter surveys and mark and recapture because there were illegal marijuana gardens with armed guards throughout the duration of this study.

Movement

Patterns of movement and stasis among foothill yellow-legged frogs in the Coyote Creek watershed were highly seasonal and associated with breeding. Over ninety percent of marked frog movements were either to the breeding area or away from it after spawning. Few frogs stayed in one location during the pre-spawn/spawning season, which is February through May (Figure 12).

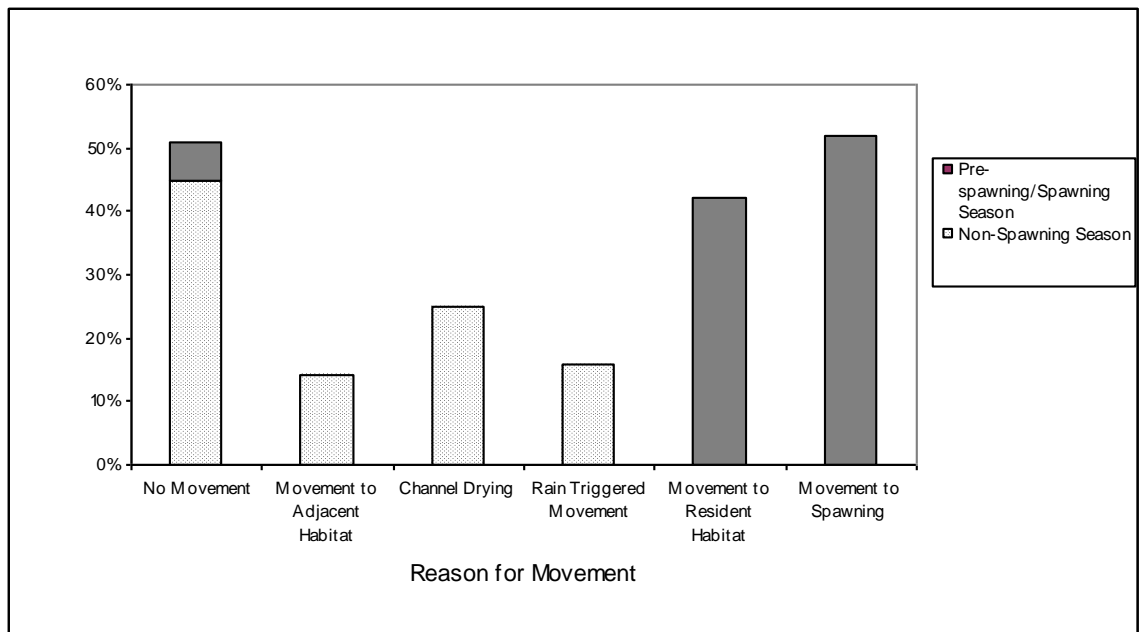


Figure 12. Purpose for maximum movement of recaptured frogs during different seasons.

By contrast, nearly half of the marked frogs did not move during the non-spawning season, defined as June through January. Fourteen percent made very small movements to adjacent mesohabitats. Movements to adjacent habitats were almost invariably either between pools and riffles or from one step pool to another. All significant movements were made in response to either channel dry backs or rain events. The maximum distance traveled by any frog was just under 2,500 m during spring 2005 (Figure 13).

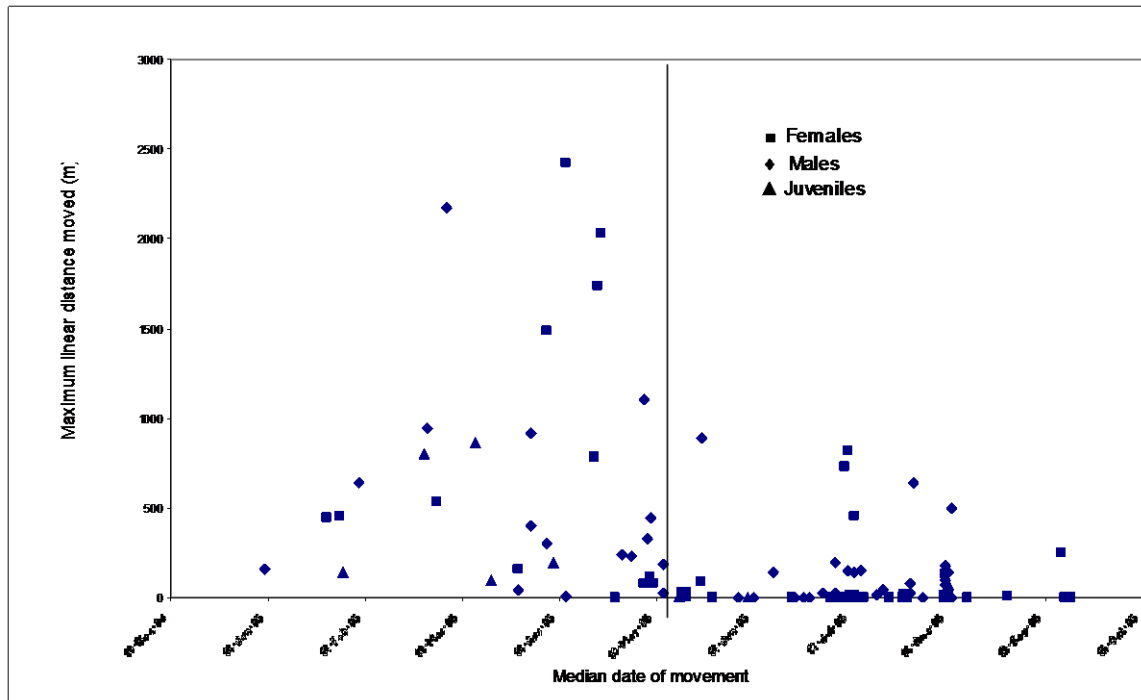


Figure 13. Maximum distances travelled for individual frogs during the pre-spawning/spawning and non-spawning seasons.

This frog was an adult female moving from the breeding area to her residential habitat in Sheep Ridge Creek (a tributary) after breeding. She was initially captured and marked on 10 April 2005, and last recaptured on 29 June 2005. The maximum distance traveled by an adult male was just less than 2,000 m. This frog moved from its residential habitat to the breeding area during early spring 2005. The maximum distance traveled by a juvenile frog was just short of 800 m. This frog moved from the mainstem of Coyote Creek (lower reach) upstream into Dexter Creek. Diurnal daily movements of telemetered frogs during summer ranged between 0 to 4 m. The average movement was less than 0.30 m.

I used maximum distances moved for every frog captured at least twice for comparison between pre-spawning and non-spawning seasons. Maximum distances frogs

traveled by season are plotted against the median date between successive captures within the season (Figure 13). Maximum distances traveled by all frogs (pooled) during the pre-spawn/spawning season were significantly greater than the non-spawning season. (paired 2-tailed t-test; critical $t = -4.619$; calculated $t = -4.205$, $p = 0.001$, $\alpha = 0.05$). Mean maximum distances traveled by all frogs during the pre-spawning season were 543 m and 104 m during the non-spawning season. Maximum distances traveled by adults during the pre-spawn/spawning season were significantly greater than the non-spawning season. (paired 2-tailed t-test; critical $t = -4.727$; calculated $t = -4.029$, $p = 0.001$, $\alpha = 0.05$). Mean maximum distances traveled by adults during the pre-spawning season were 593 m and 107 m during the non-spawning season. Maximum distances traveled by females during the pre-spawn/spawning season were significantly greater than males. (paired 2-tailed t-test; critical $t = -1.107$; calculated $t = -1.039$, $p = 0.277$, $\alpha = 0.05$). Mean maximum distances traveled by females during the pre-spawn/spawning season were 744 m and 485 m for males. Mean maximum distances traveled by adults during the pre-spawning season were 593 m and 305 m for juveniles. This difference between maximum distances traveled by adults versus juveniles during the pre-spawning/spawning season (non-parametric Kruskal-Wallis; critical $t = 1.090$; calculated $t = 1.593$, $p = 0.286$, $\alpha = 0.05$). No detectable patterns could be discerned for movements of frogs captured during fall 2004 and subsequent capture in 2005 (Figure 14).

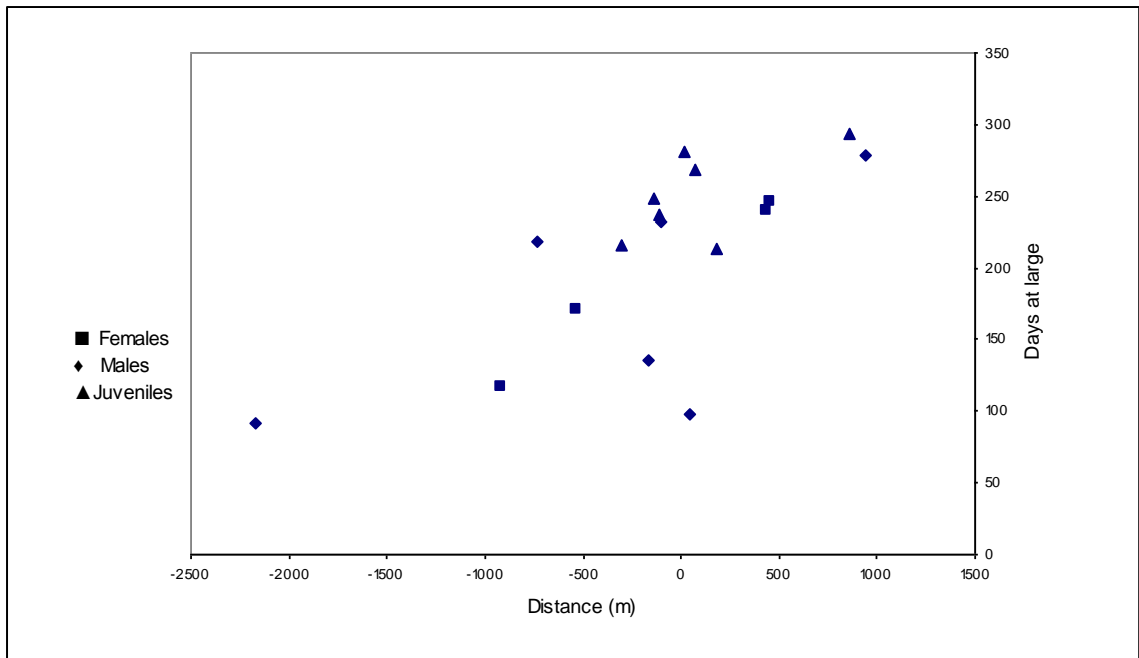


Figure 14. Relative movement patterns of foothill yellow-legged frogs between fall 2004 and subsequent capture during 2005 on Coyote Creek.

Number of days at large had no apparent influence on the distance traveled from fall 2004 to subsequent capture during 2005. Females, males and juveniles moved both upstream and downstream during this period. However, when all frogs are pooled; there is a regression that shows longer distances traveled upstream with more days at large.

The magnitude of breeding season movements of female and male tributary residents was almost invariably greater than mainstem resident frogs. Figures 15 through 18 show the movement histories of mainstem and tributary (Dexter Creek) resident females and males.

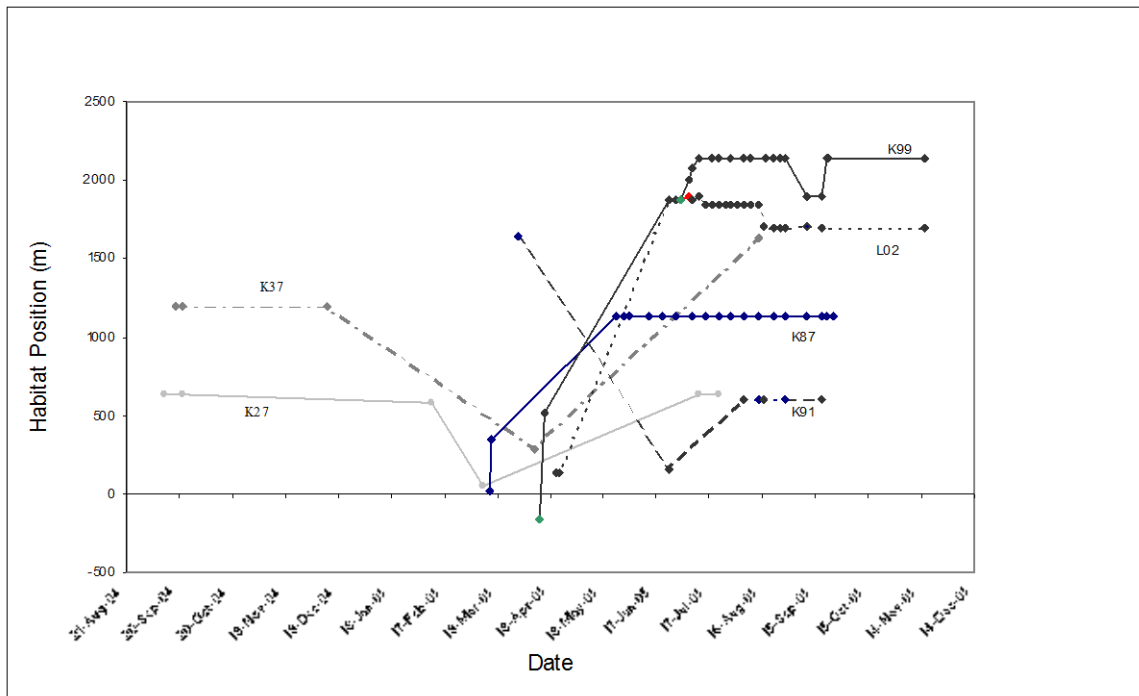


Figure 15. Movement histories of individual resident tributary females.

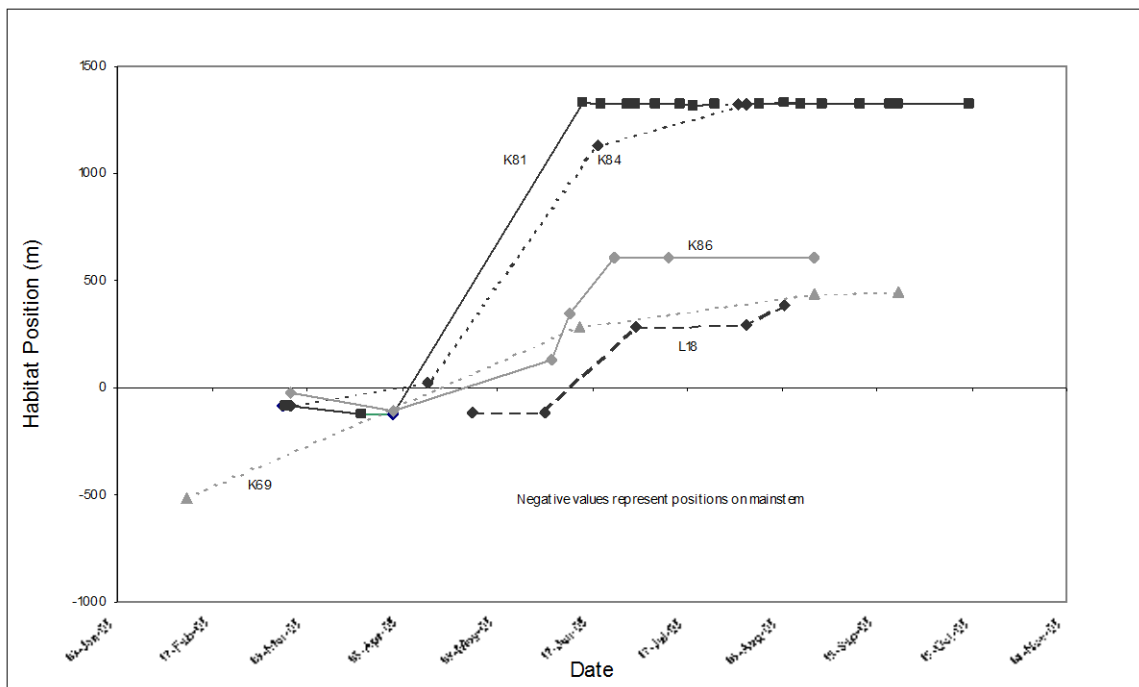


Figure 16. Movement histories of individual resident tributary males.

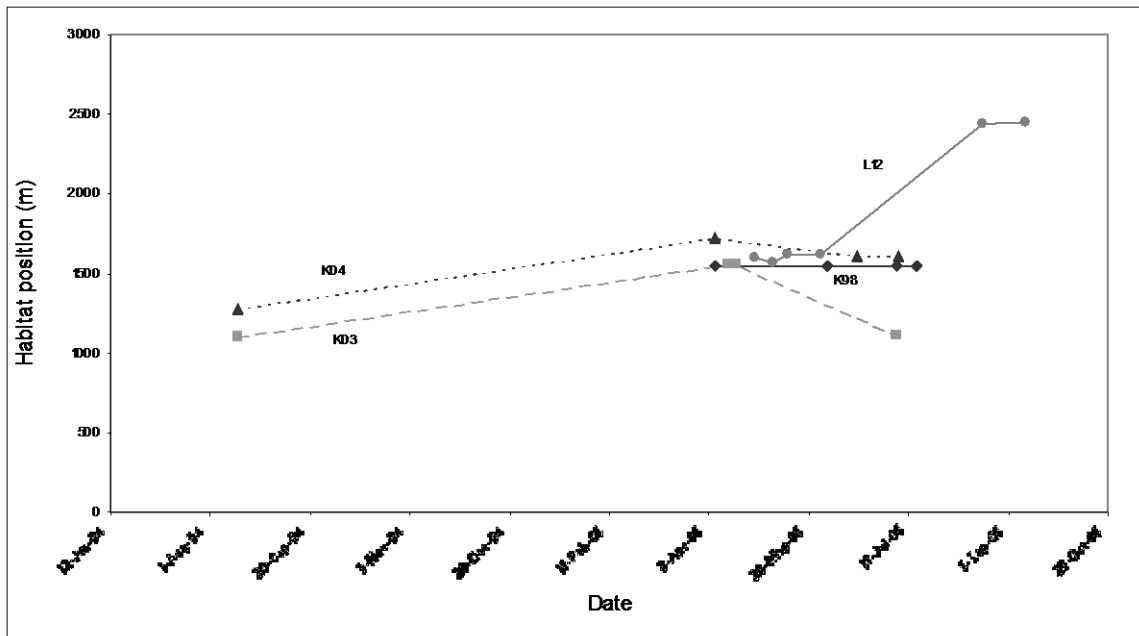


Figure 17. Movement histories of individual mainstem resident females on Coyote Creek.

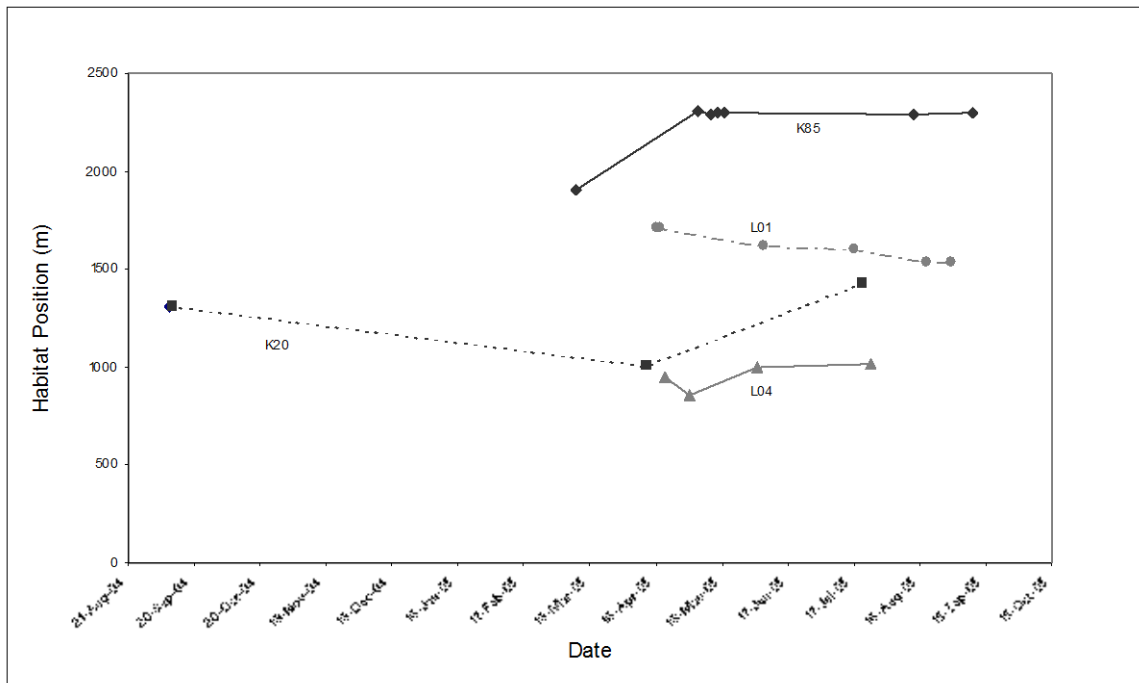


Figure 18. Movement histories of individual mainstem resident males on Coyote Creek.

Negative y-axis values represent distances traveled by resident tributary frogs on mainstem Coyote Creek (lower reach) from the confluence with Dexter Creek. Almost all frogs moved greater distances during the pre-spawning/spawning season than during the non-spawning season. Resident tributary females generally occupied habitats further away from the mainstem than resident tributary males during the non-spawning season. Most frogs of both sexes generally moved little or not at all on both the mainstem and tributary during this time. However, significant movements were made during the non-spawning season in response to dry backs and two rain events during the summer of 2005 (Figures 15, 16, 17 and 18).

Radiotracking Efficiency

Detectability of marked, stationary non-radiotagged frogs varied between 12-67 percent for individual frogs captured repeatedly on Dexter Creek during the radiotracking surveys (Table 11).

Table 11. Detectability of non-radiotagged stationary adult foothill yellow-legged frogs on Dexter Creek concurrent with radiotracking.

Frog I.D.	Sex	Number of radiotracking surveys	Number of detections	Detectability
K84	Male	18	3	17%
K91	Female	7	4	57%
L44	Female	12	8	67%
L48	Female	26	3	12%
L49	Male	15	7	47%
L57	Male	19	4	21%
L64	Male	12	5	42%
L73	Male	8	3	38%
Total/Average		117	37	32%

Marked, un-radiotagged frogs were detectable about one third of the time on average.

Nearly all un-radiotagged frogs detected were basking (Figure 19).

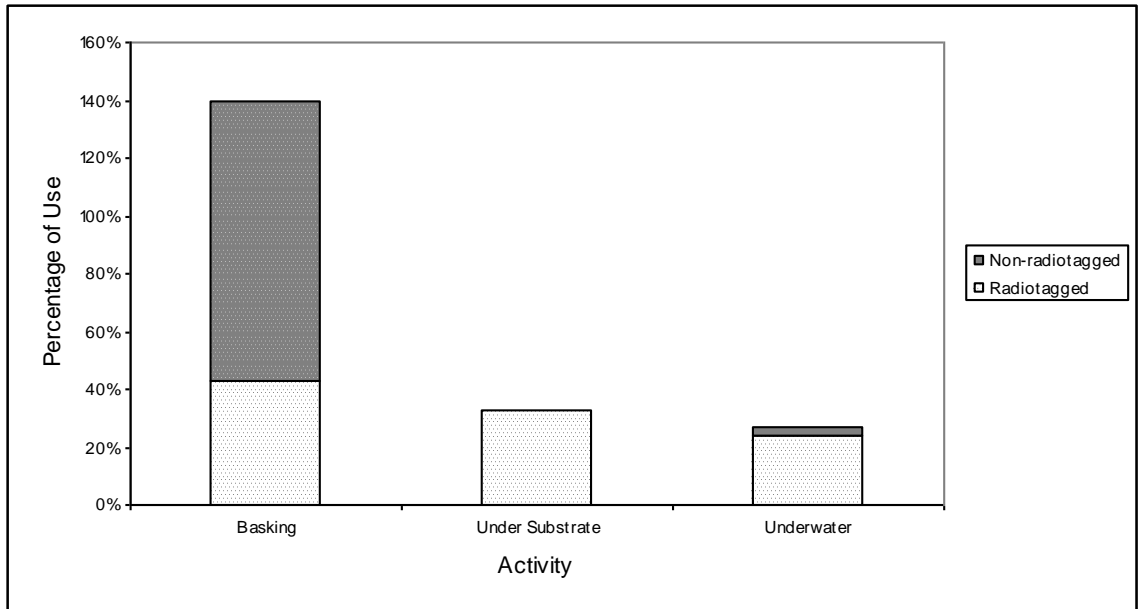


Figure 19. Observed activities of radiotagged vs. non-radiotagged frogs on Dexter Creek.

As a result of 100 percent detectability; one third of radiotagged frogs were found to be under substrate and one quarter underwater. Detectability of un-radiotagged frogs in the water was low relative to radiotagged frogs (Figure 20).

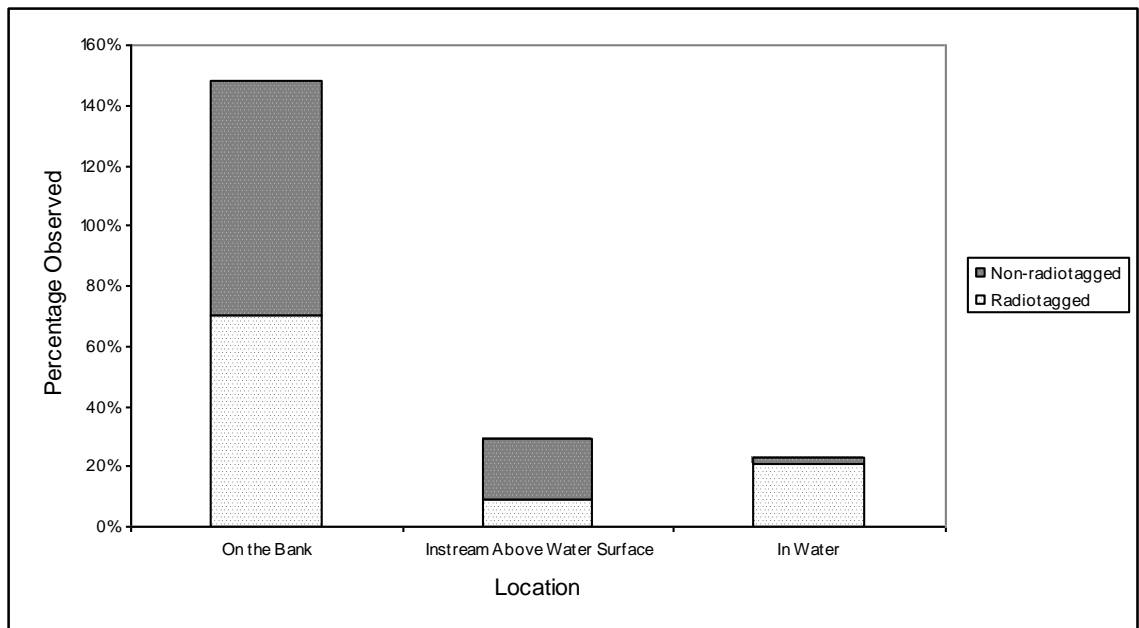


Figure 20. Location of radiotagged vs. non-radiotagged frogs in relation to the active channel on Dexter Creek.

Nearly three quarters of both radiotagged and un-tagged frogs were observed on the bank. Detectability of un-radiotagged frogs is high when they are using cobble or gravel bars, but very low when using boulders (Figure 21).

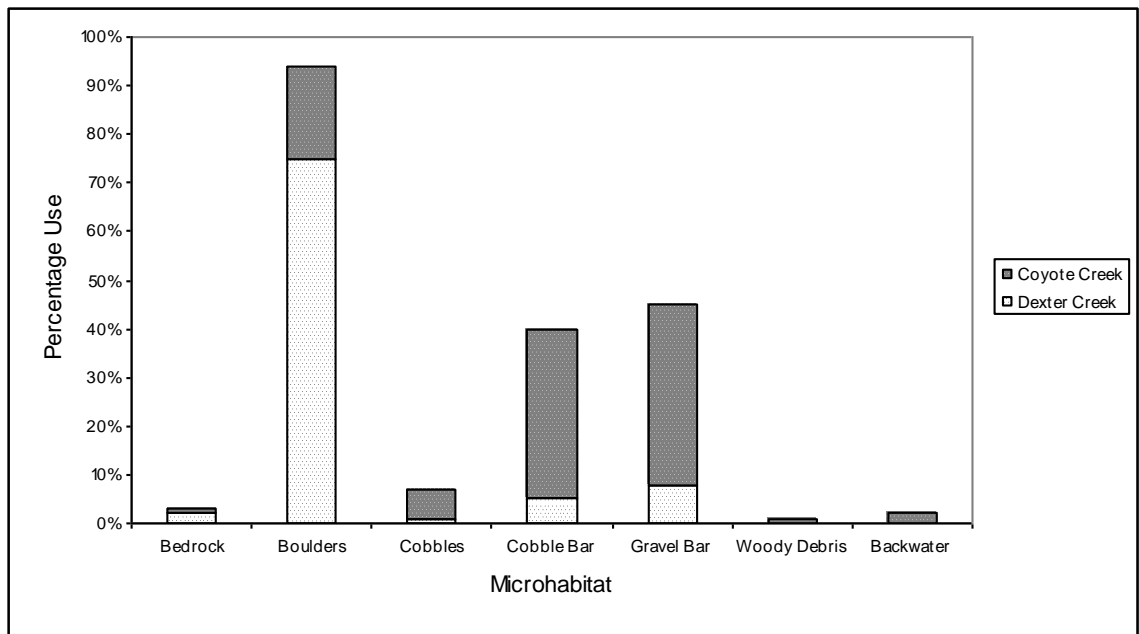


Figure 21. Microhabitat use by foothill yellow-legged frogs on Coyote and Dexter Creeks.

Detectability of un-radiotagged is relatively low at the heads of pools compared with the middle and tail (Figure 22).

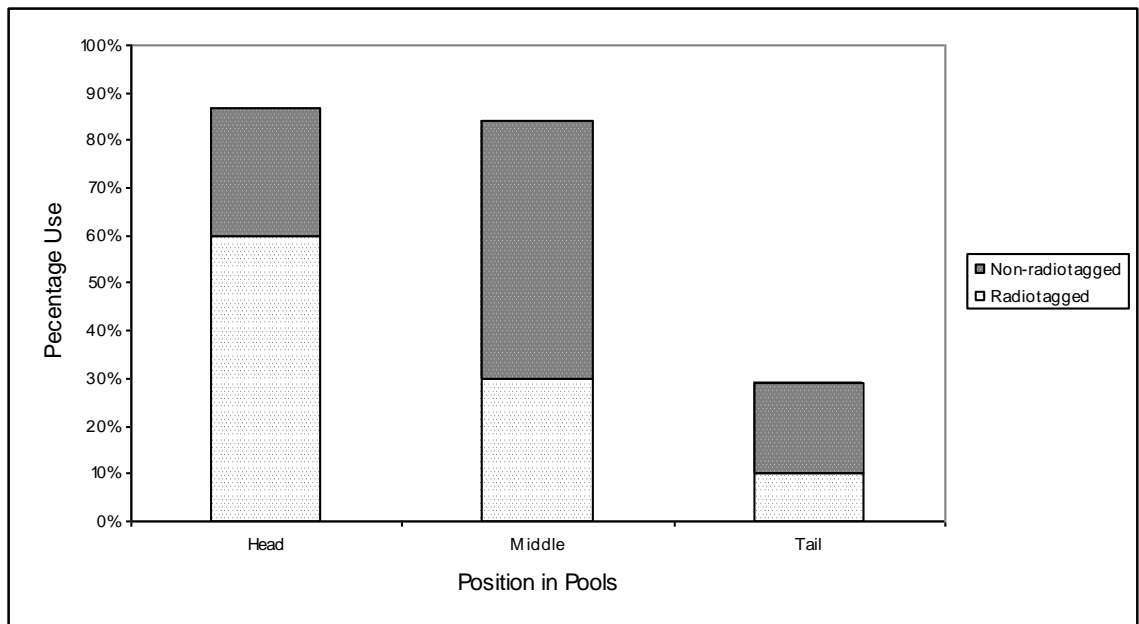


Figure 22. Position in pools for radiotagged vs. non-radiotagged foothill yellow-legged frogs on Dexter Creek.

The efficiency of bio-telemetry shows adults use of pool heads well over half the time.

Growth

Growth curves predicted by the Von Bertalanffy Growth Equation closely resemble observed growth rates of young of the year foothill yellow-legged frogs through adulthood on Coyote Creek (Figure 23).

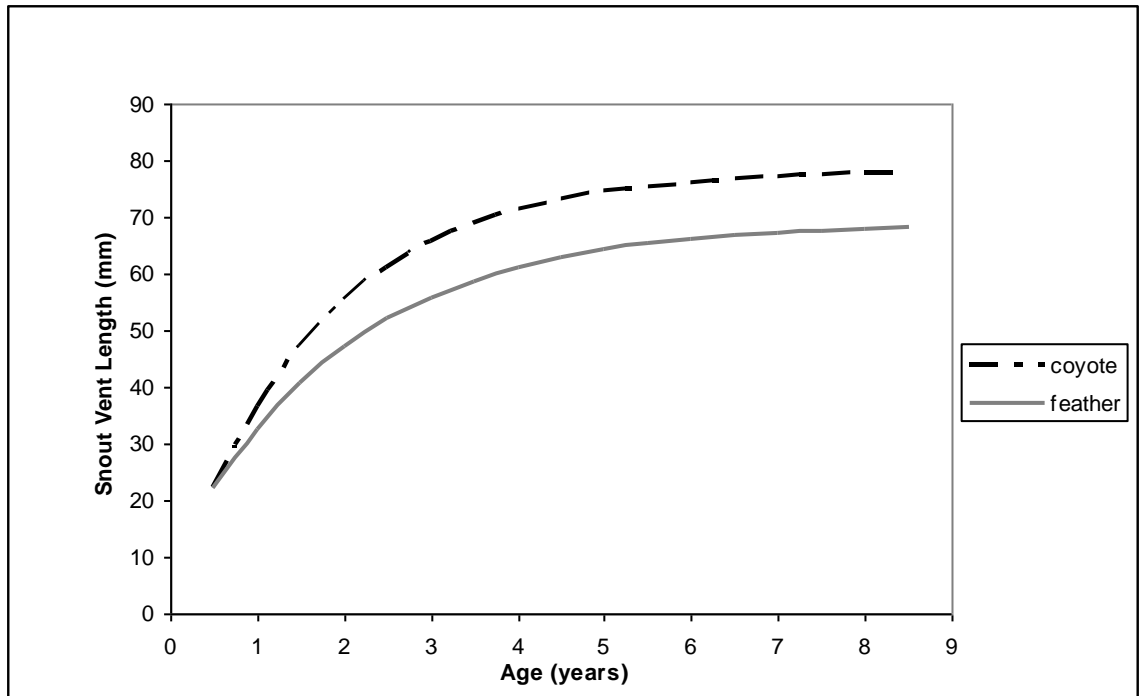


Figure 23. Comparison of growth rate predicted by VBGE setting metamorphosis at 22 mm.

Predicted growth curves show frogs on Coyote Creek reach near minimum adult size (40 mm) by the end of their first year. By contrast, predicted growth rates for Feather River frogs of the 2004 cohort show one year old frogs much smaller than minimum adult size by the end of their first year. I sampled six pools (approximately 200 young of the year frogs) within both breeding sites during mid to late October 2004. The range of average SVL lengths was 34.5-38.5 mm. Observed daily growth rates varied widely, but were generally higher than predicted daily growth rates (Figure 24).

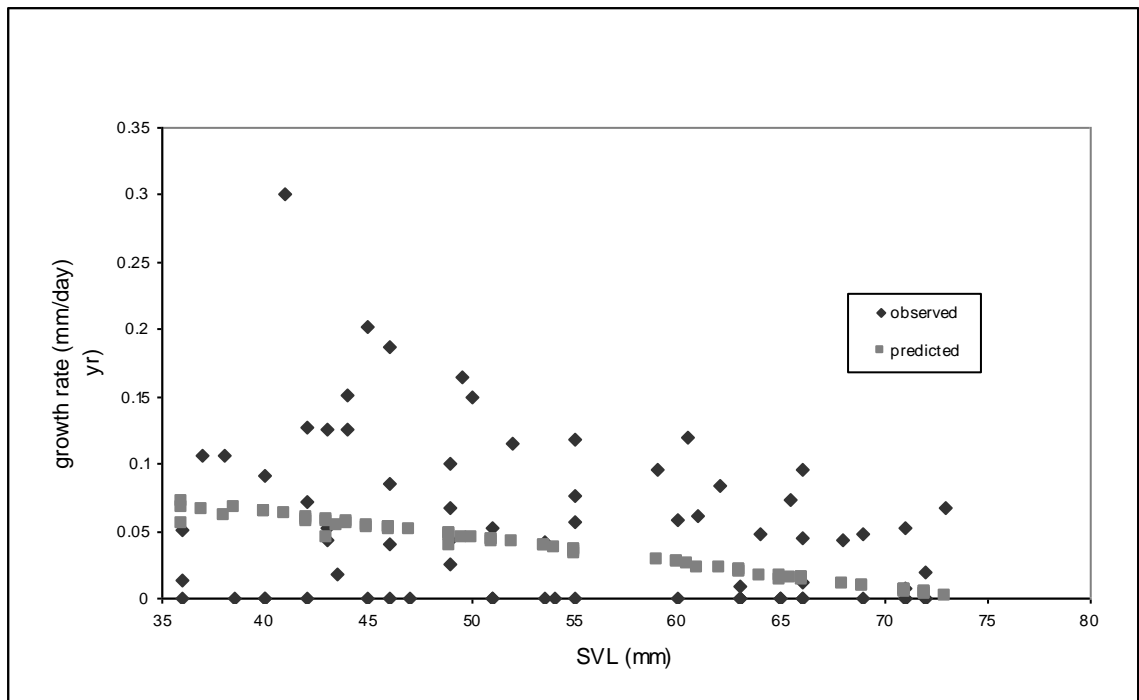


Figure 24. Daily observed and predicted adult female growth rates.

Observed growth rates from selected adult females were most similar with smaller 17 mm transformation predicted growth curves (5G female VBGE). Males and females exhibited their highest growth rates as sub-adults and small adults less than 50 mm (Figure 25).

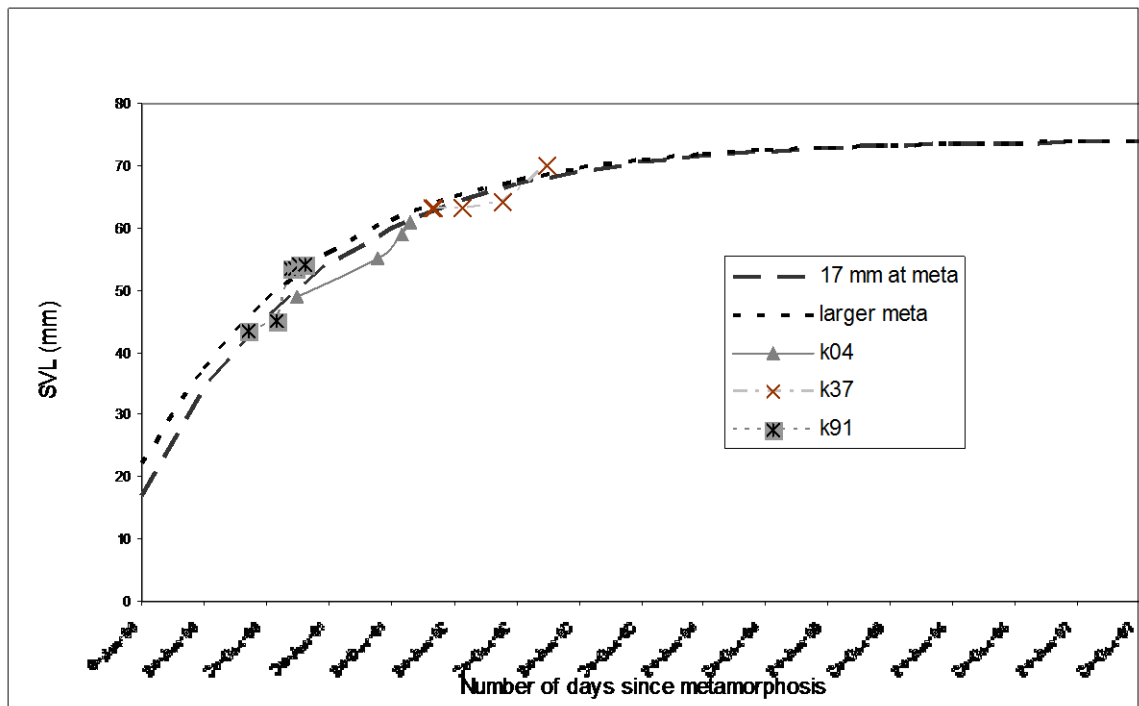


Figure 25. Observed individual female growth rates vs. growth curves for small and large metamorphs.

Female foothill yellow-legged frog growth (length) ceases after they reach near 70 mm on Coyote Creek. Females 70 mm SVL or larger needed at least three years to reach this length. Females that were near or less than 40 mm during spring 2004 were on trajectory to finish their second year near 50 mm (Figure 26).

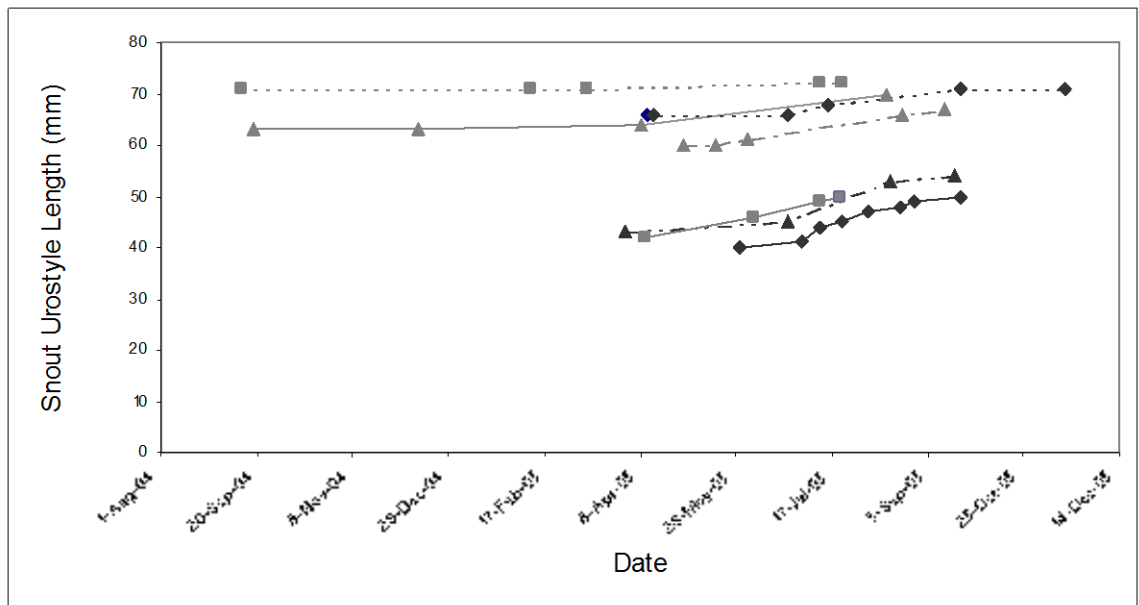


Figure 26. Selected female growth curves during 2004-2005.

I captured a female that measured 36 mm SVL on 24 September 2004 and recaptured her measuring 51 mm on 15 July 2005. Male foothill yellow-legged frog growth stops soon after they exceed 50 mm and top out near 55 mm. Males that started spring 2005 between 30 and 40 mm SVL, may reach 50 mm by the end of the year (Figures 27 and 28).

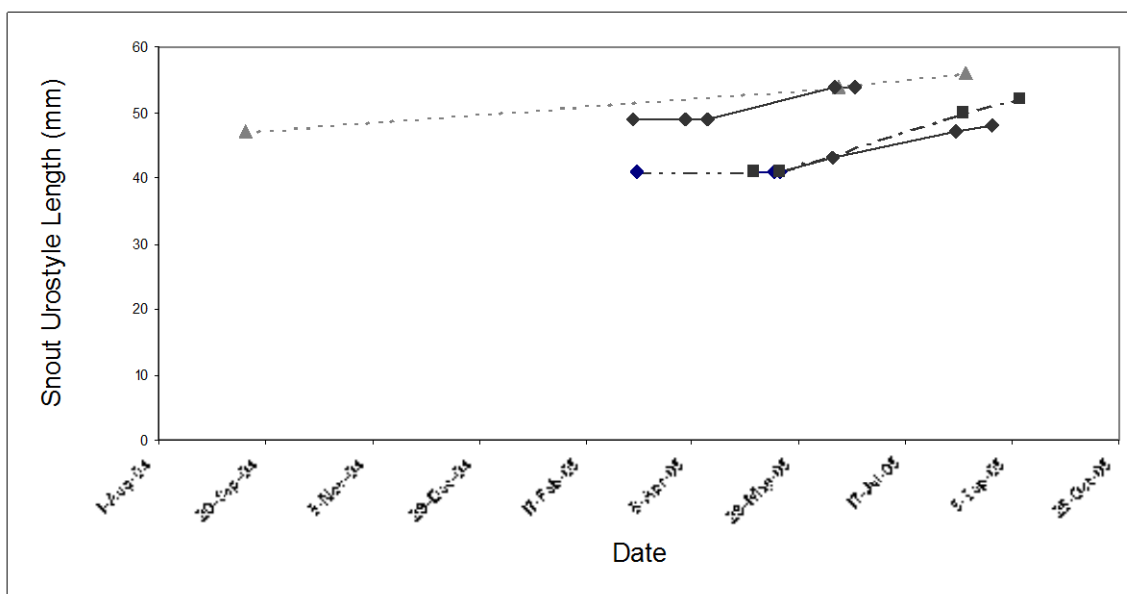


Figure 27. Selected male growth curves during 2004-2005 #1.

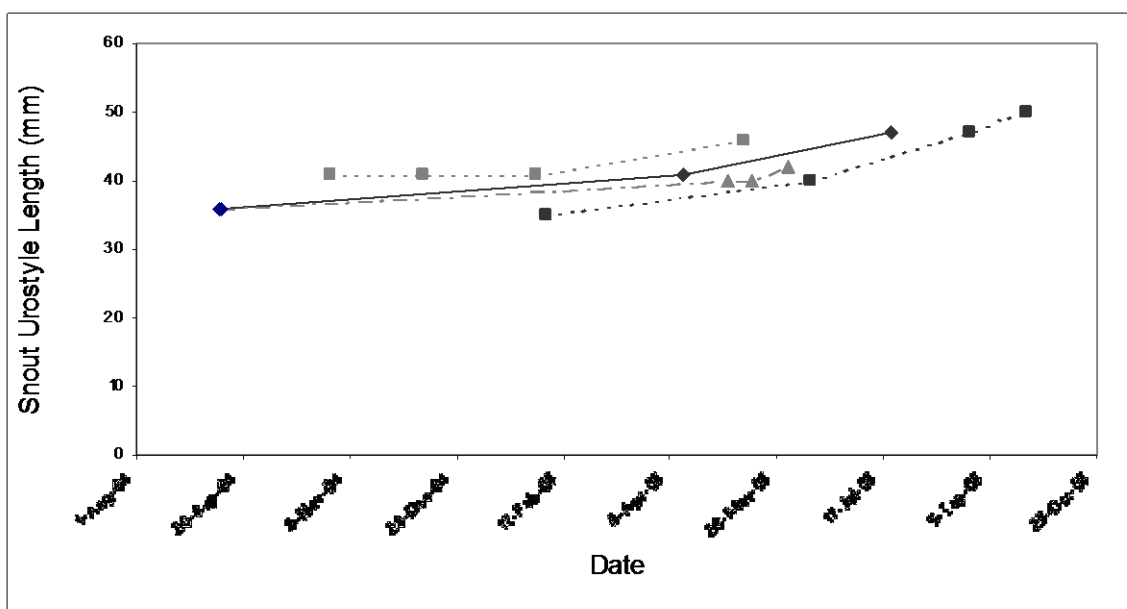


Figure 28. Selected male growth curves during 2004-2005 #2.

Condition factors for adult female tributary residents (mean = 11.7) were significantly greater than those who resided on the mainstem (mean = 11.2) (calculated $t = -2.539$,

critical $t = 1.984$, $\alpha = 0.05$, $p = 0.013$). Condition factors did not differ significantly between resident mainstem and tributary resident frogs when all frogs were pooled (calculated $t = -10854$, critical $t = 1.97$, $\alpha = 0.050$, $p = 0.065$). Average daily summer air temperatures during the summer of 2005 were significantly cooler on Dexter Creek than on the lower reach of the mainstem (Figure 29).

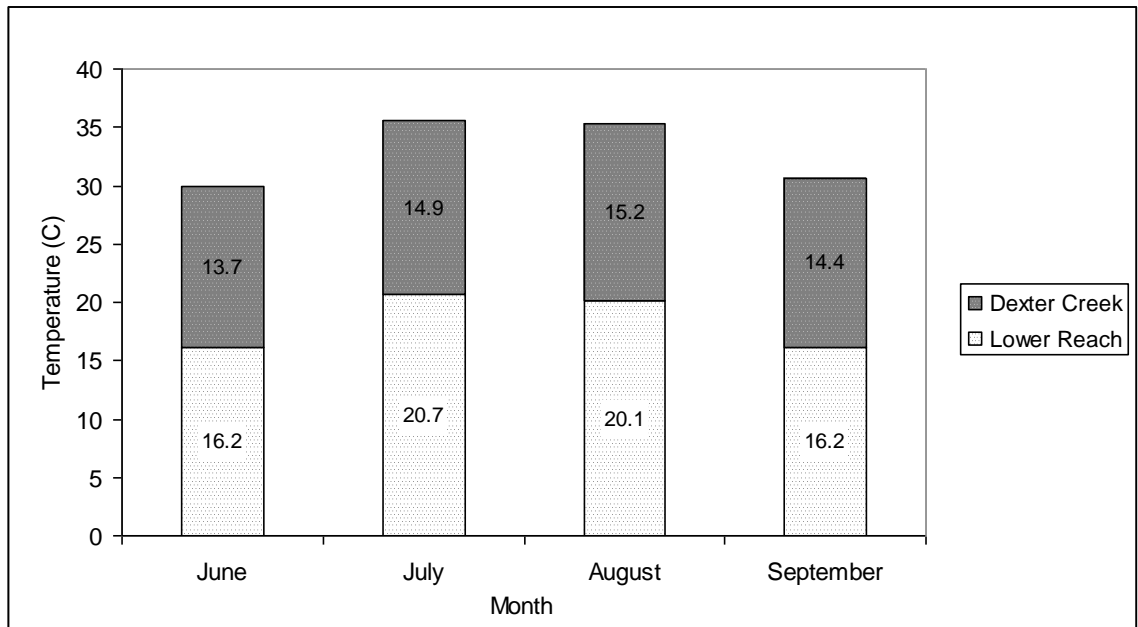


Figure 29. Comparison of average daily mean air temperatures during summer 2005, between the lower reach and Dexter Creek.

Habitat Mapping

Available Habitat

A total of 8.56 km (28,013 ft; 5.305 mi) was habitat mapped on the mainstem of Coyote Creek from the high water mark at the inlet to Coyote Reservoir to the last perennial pool associated with the upper reach breeding site below Gilroy Hot Springs. The lower and upper reaches were two distinct breeding sites that comprised all habitats

used for breeding and rearing within the study area. The middle reach separates the lower and upper reach and contained no breeding habitat for foothill yellow-legged frogs.

Surface flows were not observed anywhere on this reach after July during 2003–2006.

This reach was completely contained within a short, wide alluvial valley that separates the perennial/intermittent habitats of the lower and upper reaches. In addition, 1.15 km (7,020 ft; 1.33 mi) of Dexter Creek an intermittent stream, was mapped from the confluence with the mainstem Coyote Creek to the furthest upstream perennial pool.

Lower Reach

The lower reach stretched 2.38 km (7,797 ft; 1.47 mi) from the high water mark of Coyote Reservoir past the confluence with Dexter Creek to the terminus of the alluvial valley. The channel morphology was almost all (Rosgen Level II C Channel) slightly entrenched, highly sinuous with a moderate to high width/depth ratio (Rosgen 1996) (Figure 30).

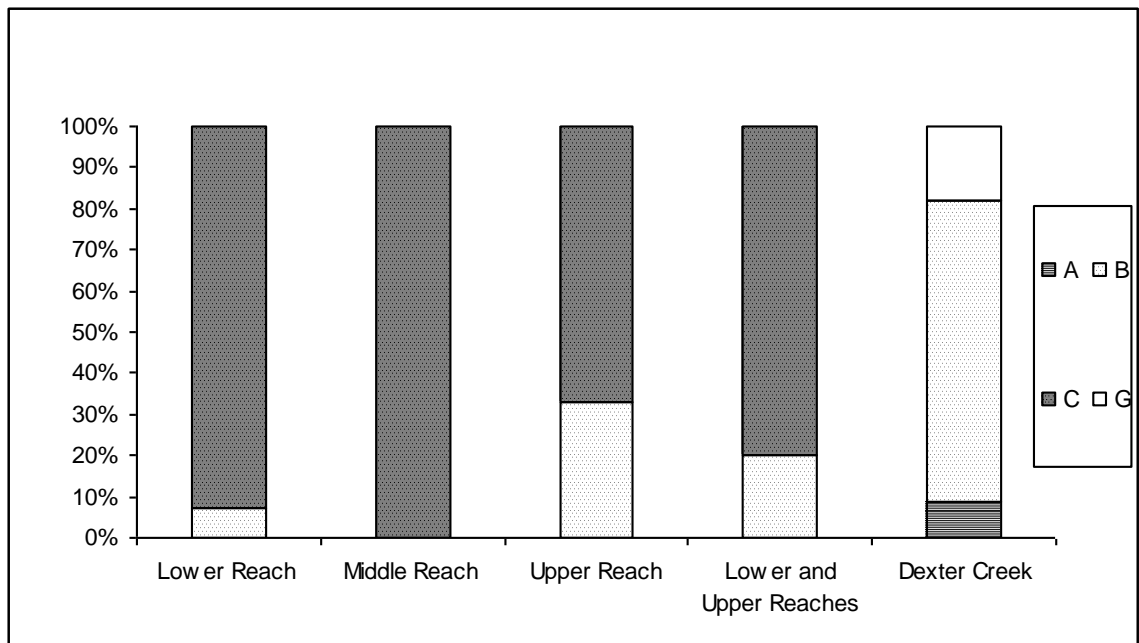


Figure 30. Rosgen Level II Channel morphology composition by reach for the Coyote Creek study area.

There was a small section associated with the Dexter Creek confluence that was (B channel) moderately entrenched, moderately sinuous with a moderate to high width/depth ratio. Three quarters of the mesohabitat composition were pools separated by riffles and flatwater (Figure 31).

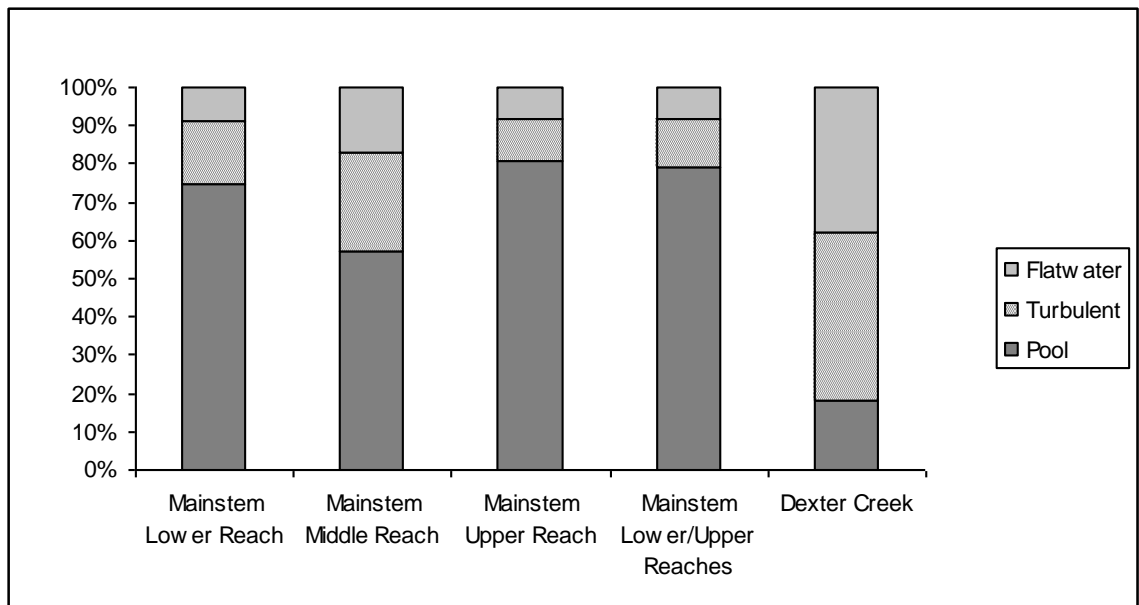


Figure 31. Mesohabitat composition for the Coyote Creek study area.

The reach had a mean width of 5.8 m (19 ft), with pools having the widest and deepest habitat. Open canopies were the norm on the lower reach with an average of 20 percent coverage (Table 12).

Table 12. Mesohabitat physical parameters for the Coyote Creek study area.

Physical Habitat Parameters	Length (ft.)	Mean Width (ft.)	Mean Depth (ft.)	Mean Maximum Depth (m)	Mean Canopy (%)
Mainstem Lower Reach					
Pool	1788	7.01	0.27	0.76	17
Turbulent	374	4.88	0.08	0.14	24
Flatwater	216	3.05	0.11	0.21	21
Total Reach	2377	5.79	0.18	0.46	20
Mainstem Middle Reach					
Pool	2150	7.62	0.40	0.95	15
Turbulent	973	4.57	0.08	0.15	20
Flatwater	636	3.96	0.10	0.21	16
Total Reach	3704	5.79	0.22	0.51	17
Mainstem Upper Reach					
Pool	1991	5.79	0.34	0.67	41
Turbulent	273	4.27	0.08	0.15	55
Flatwater	195	4.27	0.11	0.22	44
Total Reach	2459	5.18	0.22	0.44	46
Mainstem Lower/Upper Reaches					
Pool	3779	6.40	0.31	0.71	32
Turbulent	647	4.57	0.08	0.15	41
Flatwater	411	3.96	0.11	0.22	36
Total Reach	4837	5.49	0.20	0.45	36
Dexter Creek					
Pool	1057	2.04	0.23	0.41	91
Turbulent	754	2.44	0.09	0.16	91
Flatwater	329	2.13	0.08	0.18	91
Total Reach	2140	2.20	0.16	0.29	91

Cobble and gravel composed most of the dominant and sub-dominant substrate with some boulders and a small amount of sand (Table 13).

Table 13. Dominant and sub-dominant substrate by reach for the Coyote Creek study area.

	Sand	Gravel	Cobble	Boulder
Lower Reach				
Dominant	9%	41%	43%	7%
Sub-Dominant	12%	38%	32%	18%

Table 13. Dominant and sub-dominant substrate by reach for the Coyote Creek study area (continued).

	Sand	Gravel	Cobble	Boulder
Middle Reach				
Dominant	1%	34%	64%	1%
Sub-Dominant	12%	35%	20%	33%
Upper Reach				
Dominant	28%	40%	31%	1%
Sub-Dominant	3%	23%	46%	28%
Lower/Upper Reaches				
Dominant	20%	40%	36%	4%
Sub-Dominant	8%	36%	50%	30%
Dexter Creek				
Dominant	0%	24%	23%	53%
Sub-Dominant	1%	13%	48%	38%

Substrate and aquatic vegetation (algae) were the most common escape cover with pools having a relatively high cover complexity (variety of cover types) (Table 14).

Table 14. Escape cover availability for foothill yellow-legged frogs in the Coyote Creek study area.

	Average number of Cover Types	Substrate	Surface Turbulence	Depth	Undercut Banks	Rootwad	Wood	Trees	Grass/ Sedge	Aquatic Vegetation
Lower Reach										
All Habitats	3.4	98%	45%	26%	10%	10%	7%	60%	5%	83%
Flatwater	2.75	100%	25%	0%	0%	0%	0%	75%	0%	75%
Pool	3.71	95%	5%	52%	19%	19%	14%	76%	5%	86%
Turbulent	3.18	100%	100%	0%	0%	0%	0%	35%	6%	82%
Middle Reach										
All Habitats	2.6	99%	38%	20%	3%	24%	7%	13%	1%	50%
Flatwater	1.9	100%	21%	0%	0%	7%	0%	14%	0%	50%
Pool	2.9	97%	0%	44%	6%	44%	15%	24%	3%	56%
Turbulent	2.43	100%	93%	0%	0%	7%	0%	0%	0%	43%
Upper Reach										
All Habitats	3.4	100%	45%	23%	3%	0%	2%	64%	63%	24%
Flatwater	2.9	100%	50%	0%	0%	0%	0%	5%	4%	2%
Pool	3.8	100%	47%	44%	6%	0%	3%	94%	97%	94%
Turbulent	3.1	100%	100%	0%	0%	0%	0%	64%	50%	18%
Lower/Upper Reaches										
All Habitats	3.4	99%	45%	25%	25%	26%	27%	28%	29%	30%
Flatwater	2.8	100%	42%	0%	0%	0%	0%	67%	33%	42%
Pool	3.7	98%	16%	46%	11%	7%	7%	68%	46%	64%
Turbulent	3.1	98%	85%	0%	0%	0%	0%	50%	30%	45%
Dexter Creek										
All Habitats	2.4	99%	73%	47%	9%	2%	1%	5%	0%	0%
Flatwater	1.8	100%	73%	3%	0%	0%	0%	0%	0%	0%
Pool	2.8	99%	59%	87%	16%	4%	2%	8%	0%	1%
Turbulent	2.04	100%	94%	6%	1%	0%	1%	2%	0%	0%

Middle Reach

The middle reach stretched 3.7 km (12,149 ft; 2.3 mi) through a wide, short alluvial valley to the head of the valley. The channel morphology was all (Rosgen Level II C Channel) slightly entrenched, highly sinuous with a moderate to high width/depth ratio (Rosgen 1996) (Figure 30). Slightly more than half of the microhabitat composition was pools separated by long riffles (turbulent) and runs (flatwater) (Figure 31). The reach had a mean width of 5.8 m (19 ft), with pools having the widest and deepest habitat. Open canopies were the norm on the lower reach with an average of 17 percent coverage (Table 12). Cobbles and boulders composed most of the dominant and sub-dominant substrate with smaller amounts of boulders and sand (Table 13). Substrate and aquatic vegetation (algae) were the most common escape cover with pools having a relatively high cover complexity (variety of cover types). However, the overall escape cover complexity of pools and overall reach was relatively low compared with the lower and upper reaches (Table 14).

Upper Reach

The upper reach stretched 2.47 km (8,067 ft; 1.53 mi) from the head of the alluvial valley to the last perennial pool associated with the upper breeding site below Gilroy Hot Springs. The channel morphology was about two thirds (Rosgen Level II C Channel) slightly entrenched, highly sinuous with a moderate to high width/depth ratio and the rest (B channel) moderately entrenched, moderately sinuous with a moderate to high width/depth ratio (Figure 30). Over three quarters of the mesohabitat composition were pools separated by relatively short riffles (turbulent) and runs (flatwater) (Figure 31). The

reach had a mean width of 5.2 m (17 ft), with pools having the widest and deepest habitat. Canopy coverage was over twice that of the lower and middle reaches (Table 12). Cobble and gravel composed most of the dominant and sub-dominant substrate with some boulders and sand (Table 13). Substrate, overhanging trees and overhanging grass/sedges were the most common escape cover with pools having a relatively high cover complexity as in the lower reach (Table 14).

Dexter Creek

Dexter Creek was mapped (2.15 km (7,020 ft; 1.33 mi) from the confluence with the mainstem on the lower reach to the furthest upstream perennial pool. The channel morphology was almost three quarters (Rosgen Level II B Channel) moderately entrenched, moderately sinuous with a moderate to high width/depth ratio (Rosgen 1996). Almost one fifth of the channel was entrenched with a low width/depth ratio and sinuous (G Channel), with a gullied appearance. This channel type was mostly associated with the confluence with the mainstem. The rest was (A Channel) entrenched, with low sinuosity and low width/depth ratio (Figure 30). Over eighty percent of the mesohabitat composition were turbulent (riffles and cascades) and flatwater (step runs) (Figure 31). Approximately one fifth of the reach was pool habitat. The reach had a mean width of 2.2 m (7.2 ft), with pools having the narrowest and deepest habitat. Closed canopy was typical on Dexter Creek with an average of 91 percent coverage (Table 12). Boulder and cobble composed most of the dominant and sub-dominant substrate with some gravel and almost no sand (Table 13). Substrate and surface turbulence were the most common escape cover with pools having a relatively high cover complexity (variety of cover

types). Dexter Creek habitats had the lowest cover complexity in comparison with the mainstem reaches (Table 14).

Mesohabitat Use and Preference

Adult foothill yellow-legged frogs used mesohabitats on the mainstem which were strongly associated with breeding habitats and mesohabitats on the tributary (Dexter Creek) that were in or near perennial pools. I used data from both VES and mark and recapture to determine mesohabitat preferences for adult frogs. The data used were collected from 2004 (20 April to 1 July) and 2005 (18 May to 25 July) between the cessation of breeding and loss of total aquatic connectivity due to dry backs. Mesohabitat use and preferences for juvenile frogs was not analyzed because young of the year frogs only used their natal habitat (Table 3) and the 2004 cohort measured over 40 mm by the cessation of breeding in 2005. Microhabitat comparisons between young of the year and adults were not made because sampling biases which makes these data inherently inaccurate (see radiotracking efficiency section).

Mainstem

Adult frogs used pools, particularly in comparison to turbulent mesohabitats Adult females used and preferred both pools (62 percent) and flatwater (20 percent) over turbulent habitats (chi square goodness of fit test; $v = 2$, $\alpha = 0.05$, critical $X^2 = 5.99$, calculated $X^2 = 6.52$). Adult males preferred and used pools (72 percent) more than females, but did not strongly prefer flatwater mesohabitats (9 percent) in comparison to

flatwater habitat availability (11 percent) (chi square goodness of fit test; $v = 2$, $\alpha = 0.05$, critical $X^2 = 5.99$, calculated $X^2 = 12.3$) (Table 15).

Table 15. Adult foothill yellow-legged frog mesohabitat use in the upper Coyote Creek study area.

	Pool	Turbulent	Flatwater	Totals
Mainstem Coyote Creek				
Males	72%	19%	9%	74
Females	62%	18%	20%	34
Males/Females	68%	19%	13%	108
Total Observations	72%	18%	10%	303
Available	52%	37%	11%	106
Dexter Creek				
Males	98%	2%	0%	194
Females	97%	2%	1%	236
Males/Females	97%	2%	1%	430
Total Observations	97%	2%	1%	613
Available	52%	38%	10%	317

Both males and females did not use mesohabitats dominated by sand and preferred those that were dominated by boulders in comparison to availability. Adult females strongly preferred mesohabitats dominated by boulders (50 percent) (chi square goodness of fit test; $v = 4$, $\alpha = 0.05$, critical $X^2 = 9.48$, calculated $X^2 = 408$). Males used mesohabitats dominated by gravels and cobbles in proportion close to their availability. However, they used and showed a preference to boulder dominated mesohabitats (chi square goodness of fit test; $v = 4$, $\alpha = 0.05$, critical $X^2 = 9.48$, calculated $X^2 = 182$) (Table 16).

Table 16. Dominant substrate mesohabitat use by adult foothill yellow-legged frogs in the upper Coyote Creek study area.

	Sand	Gravel	Cobble	Boulder	Bedrock
Mainstem Coyote Creek					
Males	0%	43%	31%	26%	0%
Females	0%	31%	19%	50%	0%
Males/Females	0%	39%	27%	34%	0%
Total Observations	2%	38%	27%	32%	0%
Available	20%	40%	36%	4%	0%
Dexter Creek					
Males	0%	34%	3%	63%	0%
Females	0%	24%	6%	70%	0%
Males/Females	0%	28%	5%	67%	0%
Total Observations	0%	29%	6%	65%	0%
Available	0%	24%	23%	53%	0%

Females (0.63 m) (unpaired t-test; $\alpha = 0.05$, $p = 0.010$) and males (0.68 m) (unpaired t-test; $\alpha = 0.05$, $p = 0.140$) used deeper mesohabitats in proportion to total availability (0.45 m), but the statistical significance applied to females only. Adult females preferred mesohabitats a little shadier (43 percent) than what was available on average (36 percent) (unpaired t-test; $\alpha = 0.05$, $p = 0.047$). Males did not prefer mesohabitats that provided more canopy coverage than was available on average. Males used mesohabitats with an average cover complexity about equal to that which was available on the mainstem, but females strongly preferred mesohabitats with higher (4.3) cover complexity in comparison to availability (3.4) (unpaired t-test; $\alpha = 0.05$, $p = 0.001$) (Table 17).

Table 17. Depth, canopy and cover complexity of mesohabitats used by adult foothill yellow-legged frogs in the upper Coyote Creek study area.

Mainstem Coyote Creek	Mean Maximum Depth (m)	Mean Canopy Coverage %	Mean Number of Cover Types
Males	0.68	33%	3.4
Females	0.63	43%	4.3

Table 17. Depth, canopy and cover complexity of mesohabitats used by adult foothill yellow-legged frogs in the upper Coyote Creek study area.

Mainstem Coyote Creek	Mean Maximum Depth (m)	Mean Canopy Coverage %	Mean Number of Cover Types
Males/Females	0.66	38%	3.9
Total Observations	0.75	41%	3.5
Available	0.45	36%	3.4
Dexter Creek			
Males	0.37	87%	3.7
Females	0.46	85%	3.8
Males/Females	0.42	86%	3.75
Total Observations	0.40	85%	3.6
Available	0.25	91%	2.4

Dexter Creek (Tributary)

Adult foothill yellow-legged frogs used pools over 90 percent of the time on Dexter Creek. Both females (chi square goodness of fit test; $v = 2$, $\alpha = 0.05$, critical $X^2 = 5.99$, calculated $X^2 = 106$) and males ($v = 2$, $\alpha = 0.05$, critical $X^2 = 5.99$, calculated $X^2 = 188$) strongly preferred pools and used turbulent (38 percent available) and flatwater (10 percent available) mesohabitats about 3 percent of the time (Table 15). Adult females preferentially used mesohabitats dominated by boulder substrate (70 percent) and used few dominated by cobble or gravels ($v = 4$, $\alpha = 0.05$, critical $X^2 = 9.49$, calculated $X^2 = 408$). Similarly, males preferentially used boulder dominated mesohabitats (63 percent), but in contrast showed a preference for mesohabitats that were gravel dominated (34 percent) in comparison to availability ($v = 4$, $\alpha = 0.05$, critical $X^2 = 9.49$, calculated $X^2 = 182$) (Table 16). Adult females used pools that were deeper (0.46 m) than males (0.37 m). Both females and males preferred deeper mesohabitats (0.42 m) than the total mean maximum depth available (0.25 m) (unpaired t-test; $\alpha = 0.05$, $p = <0.001$). Adult females and males combined, used mesohabitats with less canopy coverage (86 percent)

which was significantly different than the average of mesohabitats available (91 percent) (unpaired t-test; $\alpha = 0.05$, $p = <0.001$). Females and males used and preferred mesohabitats that had relatively more complex escape cover (3.75) than what was available on average (unpaired t-test; $\alpha = 0.05$, $p = <0.001$) (Table 17).

Predators

I recorded 516 observations of potential diurnal predators during 2004–2005 within the study area, which included all mainstem reaches and Dexter Creek. The 46 predator observations I recorded on Dexter Creek comprised less than 10 percent of the total observations within the study area. The overwhelming majority of diurnal predator observations (470) were recorded on the mainstem. Snakes, birds and larger ranid species were the significant predators observed on the mainstem (Figure 32).

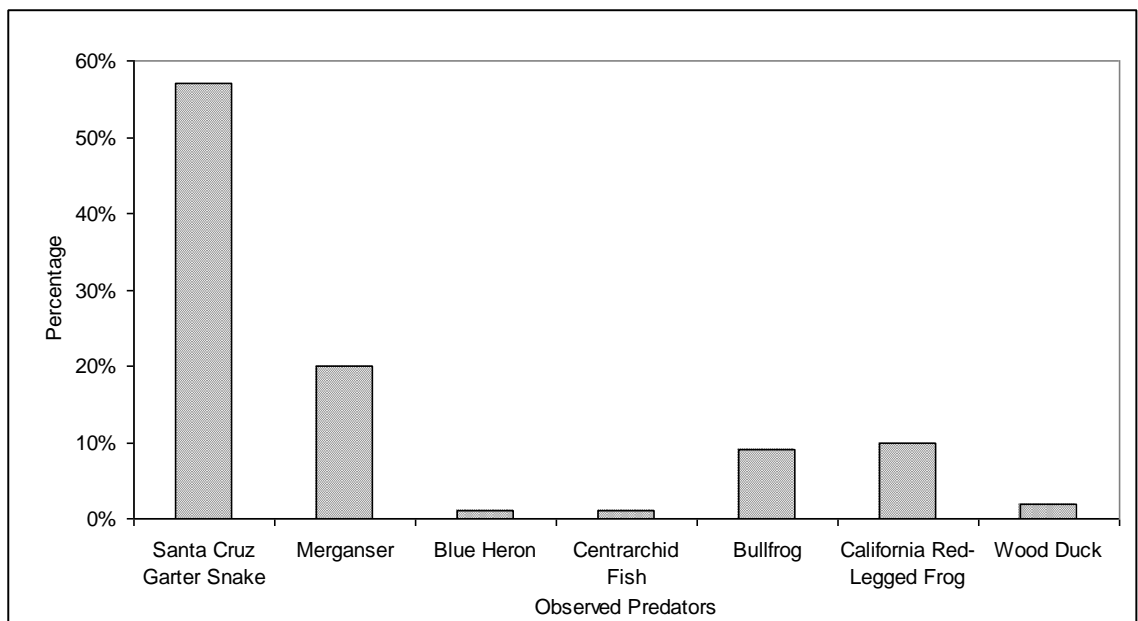


Figure 32. Observed diurnal predator composition on the mainstem of upper Coyote Creek during 2004-2005.

Santa Cruz garter snakes comprised nearly sixty percent of the observations made on mainstem Coyote Creek. I recorded a fair number of common mergansers (*Mergus merganser*), California red-legged frogs and American bullfrogs. Common mergansers comprised over 80 percent of the potential avian predators observed on the mainstem. California red-legged frogs were overwhelmingly the most encountered potential predators encountered (>90 percent) on Dexter Creek. Only a handful of Santa Cruz garter snakes were observed on Dexter Creek during the study (Figure 33).

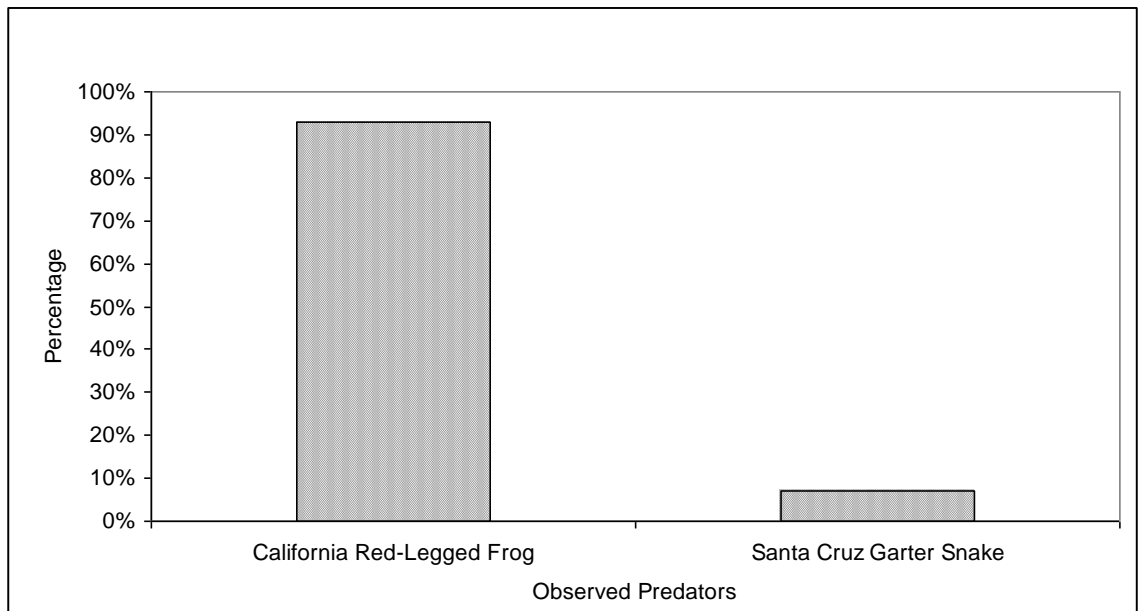


Figure 33. Observed diurnal predators on Dexter Creek during 2004-2005.

DISCUSSION

Breeding

Timing of breeding initiation was similar during 2004, 2005, and 2006, despite the vast difference in streamflows during 2004, 2005, and 2006. This suggests that photoperiod could be a strong cue for breeding initiation. However, spawning initiation on nearby Alameda Creek was 13 days later in 2005 than 2004 (Kupferberg et al. 2007). This difference may be due to lower water temperatures in 2005 than in 2004. Conditions in 2004 were drier than average in the Santa Clara Valley. Four precipitation measure stations had between 73 and 88 percent of average readings for the year. 2005 and 2006 were very wet years with ranges from 125 to 174 percent in 2005 and 112 to 165 percent in 2006. Stable spring base flows were not reached until late May in 2005 and 2006. Populations may complete breeding within a two week period (Storer 1925, Zweifel 1955), suggesting foothill yellow-legged frogs can be an explosive breeders. However, this study and one conducted on Hurdygurdy Creek (Wheeler and Welsh 2008) had a wide variability in length of breeding season between years. This suggests foothill yellow-legged frogs may be prolonged breeders instead. Wheeler and Welsh concluded initiation and length of the breeding season were strongly influenced by the natural hydrologic cycle, which may vary greatly among years. This appears to be the case on Coyote Creek. Temperatures at the onset of breeding were close to 12°C in all three years on Coyote Creek. This is consistent with most other studies, but on the low range compared to northern coast range streams and Sierra Nevada and Cascade Range foothill

streams (Zweifel 1955, Kupferberg 1996, Fuller and Lind 1991, Seltenrich and Pool 2002, Placer County Water Agency 2008). In Coyote Creek temperatures are higher than northern or mountain foothill streams at the time stream flows normally begin to decline.

The loss of 16 early, large (50–85 mm) egg masses on the lower reach in 2005 were partially mitigated by a net gain of 19 egg masses at the lower site in 2005. However, 11 of these late egg masses were less than 40 mm in diameter. Therefore, there were less eggs surviving to hatching in 2005 than 2004 on the lower reach. The upper reach had a net gain of 13 egg masses and all masses deposited in the upper reach survived to hatching in 2005. In Alameda Creek there also was a substantial gain in overall breeding output in both 2005 and 2006 in comparison to 2004 (Kupferberg et al. 2007). The higher stream flows and favorable temperature that allowed an extension in the breeding season from 2004, likely allowed for enough time for smaller yearling females to contribute to the 2005 cohort on Coyote Creek. Fifteen egg masses deposited late during the breeding season were less than 30 mm diameter in 2005, but the smallest egg mass deposited during 2004 was 38 mm. Van Wagner (1996) recorded an egg mass size range of 35–70 mm on Clear Creek in Nevada County during 1992, 1993 and 1994, and all breeding frogs were at least two years old. On Coyote Creek the breeding season was much longer on the lower reach in 2005 than in 2004 and on the upper reach in 2005. The much wider range of breeding temperatures resulted in a wider range of the number of days it took for eggs to hatch at the lower reach in 2005.

Streamflow and Breeding

All breeding occurred on descending limbs of the hydrograph and at flows less than an order of magnitude (25-30 mps [80-100 cfs]) higher than spring base flows (2.4-3.0 mps [8-10 cfs]). There was one significant descending limb of the hydrograph in 2004 and four in 2005 because of late storms during breeding in 2005. Peak streamflows were much higher in 2005 and 2006, but initiation of breeding took place within a week of each other in 2004, 2005, and 2006. It appears that magnitude of flow during the breeding season has limited effect on initiation and breeding activity on Coyote Creek during 2004–2006. Seventeen years of monitoring on the South Fork Eel River showed only a weak trend towards breeding later in the year during wet years (Kupferberg et al. 2007). They concluded timing of breeding is not associated with stage heights. Decreasing flows from storm induced peaks (descending limbs) were strongly associated with breeding activity on Coyote Creek, but breeding activity ceased when flows increased due to storms within the breeding season. Rain may suppress breeding activity once adult frogs reach the breeding locations (Kupferberg 1996a).

Large spring storms that create high magnitude stream flows have a potential to scour egg masses deposited early in the breeding season. The large storms during late March and early April in 2005 created high flows (427 cms [1,400 cfs]) that scoured nearly all egg masses deposited in March. A large late season storm occurred in 2006 at the end of March, and lasting into the middle of the first week of April generated peak flows as high as (518 cms [1,700 cfs]). Although fate of egg masses wasn't studied in 2006, most egg masses and newly hatched tadpoles present prior to the late storm were likely lost to scour

in 2006. The larger egg masses in the early part of the breeding season indicates early breeding by the largest females is a risky strategy during wet years such as 2005 and 2006. Similar losses of egg masses from scouring flows from intense late season storms and dam spillovers were documented on the Trinity River (Lind et al. 1996) and on the South Fork Eel River due to storms during 2005 (Kupferberg et al. 2007). The advantage of early breeding is likely to be that in most years, flows too low to scour egg masses, resulting in increased probability for recruitment to adulthood compared with eggs deposited later in the season, especially in drier watersheds such as Coyote Creek.

Between 1961 and 2006, there have been eight seasons in which high scouring flows (> 305 mps {1,000 cfs}) occurred after March 15. These were mostly El Niño years such as 1963, 1964, 1965, 1982, 1998, 2005, and 2006. The only exception was 1991, which was a very dry year, but with a large storm during late March. Large magnitude late season storms tended to be spaced over the years. The occasional risk to the largest, most fecund females for breeding early is relatively low over the lifetime of these individuals. Smaller females tend to breed later when the hydrograph is more stable after mid-April in central California, but part of that may be due to growth to breeding size during prolonged breeding seasons. The plastic reproductive strategy has likely allowed this species to persist in the fluctuating climatic pattern of California, which alternates between wet and very dry. All breeding habitats in Coyote Creek were perennial or adjacent to perennial habitat during all years, including the driest of years. If they successfully transform, young of the year frogs do not have to move far to find water when the habitat they were in dries.

Temperature and Breeding

Initiation of breeding in Coyote Creek occurred at temperatures very close to 12°C during the 2004–2006 breeding seasons. In addition, peak breeding activity occurred within a narrow range of temperatures (13–16°C). Data collected during several years of monitoring on different watersheds in California suggested increasing water and air temperatures likely cue breeding initiation (Kupferberg et al. 2007). Most studies to date recorded breeding initiation temperatures were close to 12°C, but initiation temperatures on the Feather River during 2004 and 2005 were at 10°C (GANDA 2008). Peak breeding during this period occurred between 12 and 15°C. No studies have documented breeding above 20°C. Van Wagner (1996) recorded breeding activity up to 20°C. Foothill yellow-legged frogs may likely have physiological constraints that do not allow them to breed above 20°C. Metabolic rates above 20°C may prevent them from expending energy towards egg production. In addition, cooler temperatures on the upper reach likely explain why it took longer (mean number of days) for egg masses to hatch in comparison to the lower reach.

Physical and Habitat Parameters for Egg Masses

Pools were used almost exclusively during the 2004 and 2005 breeding seasons. However, there was a partial shift in specific pool use in response to higher flows in 2005 and a shift in the upper reach for frogs to utilize the middle of pools as opposed to tailouts, which are more subject to scour. Early breeding frogs tended to make more use of submerged vegetation and roots as attachment substrates, possibly due to lower velocities at the edge of the channel. Larger substrates provided more of the attachment

points during the higher flows during 2005 than 2004. Fuller and Lind (1991) found that larger substrates represent the best attachment substrates, but submerged vegetation may be used. In general, frogs deposited eggs in locations closer to shore or deeper slack water areas in response to increased stream flows and velocities, resulting in a decrease in the amount of preferred spawning habitat available early in the breeding season. However, the availability of shallow, low velocity margin areas is not a breeding cue (Kupferberg et al. 2007).

Management Considerations for Breeding

Foothill yellow-legged frogs exhibit some plasticity in breeding behavior. However, management strategies that preserve or mimic the linkage of the natural hydrologic cycle and water temperatures have the best chance of allowing populations to persist through time. These strategies should minimize scouring flows and provide preferred temperatures (12–17°C) during breeding. Hydrologic and temperature regimes on central and southern coast range watersheds are very different from Cascade, Sierra Nevada and northern Coast Range streams. Runoff originates from rainfall rather than being influenced by snow melt. Runoff varies drastically from year to year on southern coast range streams, and air and water temperatures are warmer during winter and spring. These factors should be taken into consideration during planning for monitoring breeding and/or when evaluating management actions to could alter of stream flows.

Movement/Mark/Recapture

General Characteristics

Maximum SVL and weights of adult foothill yellow-legged frogs of both sexes were greater than those recorded by Van Wagner (1996) but less than those recorded by GANDA (2008). Operational sex ratios recorded on both reaches in 2005 were within the range of those recorded by Van Wagner (1996) during his three year study. Adult foothill yellow-legged frogs have been documented utilizing tributaries to breeding streams as resident habitat (PCWA 2008, Bourque 2008, Gonsolin 2005). In contrast to upper Coyote Creek, these streams were perennial. Despite the perennial nature of these breeding streams, some adult frogs elected to use intermittent tributaries as their resident habitat instead. Intermittent tributaries are even more crucial for adult frogs as resident habitat on upper Coyote Creek because surface water is scarce and unreliable from year to year on the mainstem particularly during summer and fall and some tributaries offer some perennial habitat even during the driest of years. Most adult frogs of both sexes prefer to use tributaries outside the breeding season. However, most adult males observed on the lower reach used the mainstem after the breeding season during 2004. Adult males tended to stay in the breeding areas longer than females as suggested by the heavily male biased operational daily male/female sex ratios recorded during other studies (Wheeler and Welsh 2008, Van Wagner 1996, GANDA 2007). Early dry backs from the confluences with the mainstem during a dry year such as 2004 may have prevented some males from ascending the tributaries following active breeding. The proportion of adult females residing on Dexter Creek was nearly identical during both years because females

bred and moved back up tributaries shortly after spawning. Harassment by adult males may influence post-spawn females to move away from breeding areas sooner than they otherwise would. I captured and tagged a large adult female near the confluence area and promptly released her. I observed a male and female about five minutes later locked in what appeared to be amplexus. The female turned out to be the female frog I had just marked. Daily diurnal summer movements were invariably within a single mesohabitat. Large adult frogs alternate between basking and other activities. They may move to a favored basking spot and to other positions within their home pool to forage or hide.

Movement

The spatial separation between adult resident and spawning habitat requires breeding frogs to travel long distances for the overwhelming majority of adult frogs on the lower reach during the pre-spawn/spawning season. Less than ten percent of adult frogs did not make long distance movements during the pre-spawn/spawning season because their resident habitat was in or near the breeding habitats. Resident mainstem females were shorter with less body mass than tributary residents. Size and condition of resident tributary adult females were greater than adult female residents on the mainstem. Nearly sixty percent of frogs did not make significant movements during the non-spawning season because the resident habitat was perennial and of relatively high quality. Summer dry backs made it necessary for some frogs to travel significant distances to perennial habitats. A search for less crowded and/or higher quality habitats and food resources were likely factors influencing adult frogs to take advantage of the opportunity provided by rain events to make long distance movement over dry streambeds to these habitats. The

maximum distances recorded during 2005 were much greater than those recorded by Van Wagner (1996), but much shorter than those recorded by Bourque (2008). The frogs in Van Wagner's study were primarily mainstem residents that did not need to travel far for suitable breeding habitat. By contrast, the study area of Bourque (2009) consisted of many intermittent tributaries that provided preferred resident habitat separated by great distances from the mainstem of Red Bank Creek, which provided the breeding habitat for that population. Juvenile frogs made significant movements during the pre-spawn/spawning season both up and downstream (including ascending tributaries) presumably to seek out higher quality rearing habitat away from predators and to reduce competition for resources between each other.

In addition to moving to and from breeding areas, all frogs had the option of making long distance movements for any reason from December 2004 to early July 2005 because there was connectivity (flowing water) throughout the study area. Long distance movements were restricted once channel dry backs started. Females moved greater distances during the pre-spawn/spawning season because they tended to establish residence in perennial habitats further away from the breeding areas. Males tended to make smaller incremental movements later in the year as streamflows decreased. The highest quality habitats were already occupied by large adult females by the time most males began to move in from the breeding areas. Males had to utilize habitats closer to the breeding areas that were largely by-passed by adult females. By contrast, Van Wagner (1996) did not detect a significant difference in the average maximum movements between adult females and males. This is likely because there was little or no

spatial separation between breeding sites and quality resident habitat throughout the year. The study area of Van Wagner had reliable perennial habitat that possessed all the requirements necessary for foothill yellow-legged frogs to complete their life cycles and no tributaries existed nearby. Unlike Van Wagner (1996), adults travelled much further than juveniles during the pre-spawn/spawning season. However a statistically significant difference could not be detected due to a low sample size of juveniles and the high variability of the data. I could not detect an upstream or downstream pattern of movements for all frogs between fall 2004 and subsequent recapture in 2005 because frogs moved in all directions once continuous flows were re-established. This was perhaps a density dependant dispersal behavior, due to frogs having to use scarce perennial habitat during summer and fall 2004 and the sudden availability of habitat throughout the study area once surface flows were re-established during early December, 2005.

Female Movement

Examining movement histories of individual frogs reinforces the trends observed. Large adult females (K99, L02, K37, L12) clearly made higher magnitude movements to resident habitat after breeding (Figures 15 and 17). Smaller adult females (K27, K37, K87 and K98) did not move as far away as large adult females to resident habitat from the breeding areas. A plot of distance between established residence and nearest breeding sites show a trend of larger (mass) individuals occupying habitats further away from the breeding area (Figure 34).

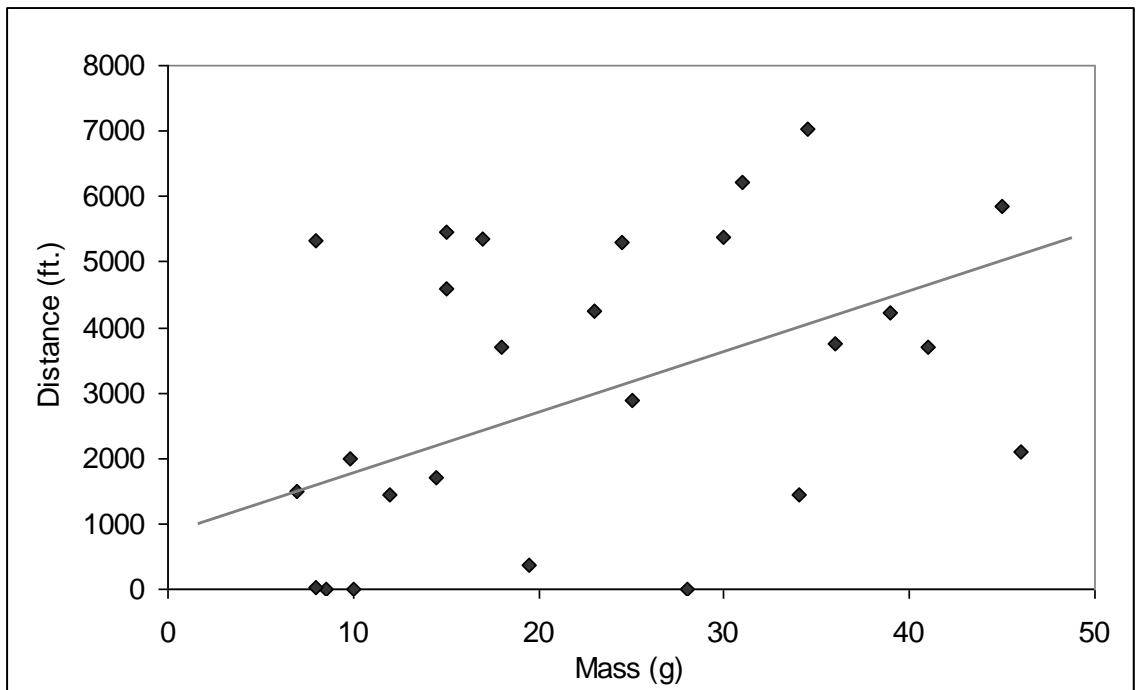


Figure 34. Female body mass of resident frogs and distance from the breeding area.

Likely, the relationship between food availability and energy expenditure is more favorable on the tributaries. One small female (K91) was initially captured over one mile upstream of the confluence on Dexter Creek early during the breeding season. She subsequently moved down to the breeding area, likely spawned late during the breeding season, then moved back up Dexter Creek to the closest perennial habitat from the confluence. This frog was a near minimum size for an adult (43 mm) at initial capture and grew to (54 mm) by the end of summer.

Male Movement

Three of four large adult males (K81, K84, K95) travelled greater distances than smaller adult males (K86, L18, K69) (Figures 16 and 18). In addition, their movements away from the breeding areas were made earlier than smaller males. This is likely

because larger males bred earlier and had the opportunity to occupy higher quality perennial habitat that was further upstream on Dexter Creek. The individual movement histories clearly show males maintained positions close to the breeding areas for longer periods of time than females. All resident tributary males made significant movements away from the mainstem perhaps to establish residence in the highest quality perennial habitat available. However, they did not attempt to occupy habitat further upstream that large females had previously occupied. Similar to their female counterparts; resident mainstem males typically moved little in comparison to resident tributary frogs during any season. A plot of distance between established residence and nearest breeding sites show a trend of larger (mass) individuals occupying habitats further away from the breeding area (Figure 35).

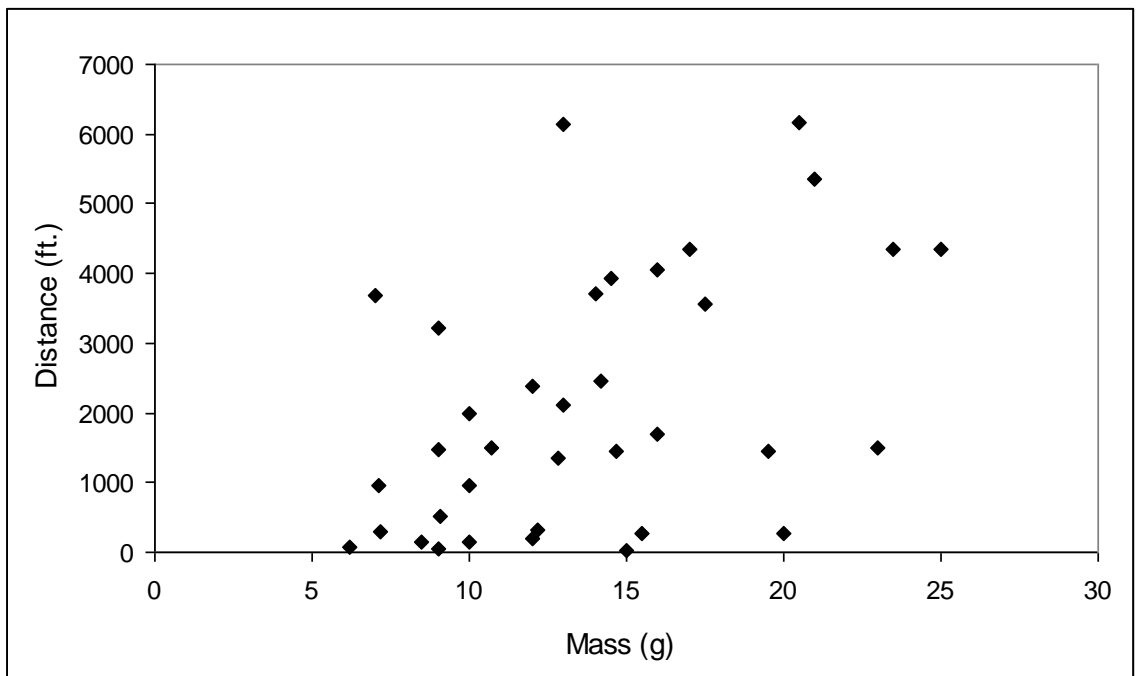


Figure 35. Male body mass of resident frogs and distance from the breeding area

July and August 2005, on Dexter Creek was approximately 5°C cooler than the nearby mainstem, which means resident frogs on Dexter Creek need about half the food to maintain body weight than the mainstem residents. This suggests the tributaries may offer physical conditions, which favor the attainment of larger body masses and therefore better condition. These frogs would have increased fitness to make the longer trips to and from the breeding areas and have higher fecundities.

Radiotracking Efficiency

Radiotracking frogs yielded far more accurate activity and micro-habitat use data than standard VES or mark and recapture. My activity results were similar to those recorded by Garcia & Associates (GANDA 2008). GANDA recorded more activity types (i.e. swimming, calling, floating, amplexus) because they collected data throughout the breeding season, when frogs were exhibiting breeding activities such as amplexus, calling, swimming and floating. I conducted radiotracking during summer and early fall when amplexus and calling were not occurring and swimming and floating were much less likely to occur. My activity category (under substrate) is largely equivalent to the GANDA activity category (hiding). I wouldn't have been able to detect frogs that were taking position under substrate using standard VES or mark and recapture surveys, unless I strategically searched under boulders. Biotelemetry enabled me to find many more frogs underwater or instream (in channel but above surface on substrate or wood), than if I used standard VES. Frogs under water may be under leaf litter, in turbulence or in the shadows and consequently very hard to detect employing VES. Frogs utilizing rootwad

or boulder microhabitats are relatively difficult to detect in comparison to other microhabitat categories. Frogs basking on gravel or cobble bars were the easiest to detect using VES, because they were out in the open and were in contrast to the uniform substrate. Frogs were considerably more difficult to see when positioned at the head of pools in comparison to the middle or tail gravel and cobble bars. Pool heads were primarily composed of boulder and cobbles, which break up the silhouette of a frog body. Scanning the heads of pools with binoculars with good optics before disturbing the frogs can aid in detection. Also, spending proportionally more time closely inspecting these areas can help mitigate detection deficiencies employing standard VES surveys.

Biotelemetry would have yielded much more precise and accurate movement data during the pre-spawn/spawning season than standard mark and recapture methods. Biotelemetry would have enabled me to collect data that could be used to calculate movement rates, precisely compare initial movements to the breeding sites with physical parameters such as temperature and stream flows. Accurate data pertaining to movement and habitat use during late winter and early spring would have been feasible using biotelemetry. Monitoring movements from resident habitat to the breeding sites would have been possible during a very wet late winter and early spring such as 2005.

Growth

In part, the patterns observed in this study of coastal frogs with respect to size and growth; seem to follow those observed for a Sierra Nevada foothill population studied by Van Wagner (1996). Females exhibit greater growth rates and reach much larger sizes than males. However, there wasn't a high variability of young of the year growth for the

2004 cohort on Coyote Creek as those observed by Van Wagner (1996). Most of the rearing habitats for foothill yellow-legged frogs had canopy coverage less than 60 percent. Many portions of Van Wagner's study area had canopy coverage greater than 90 percent. This affects water temperatures, primary productivity and consequently insect availability for food. As a consequence, one would expect longer development times for tadpoles to reach metamorphosis. Precipitation varied between 2004, a dry year with a short breeding season, and 2005 with a long breeding season, which was a very wet year. All tadpoles transformed prior to July 1 within the Coyote Creek study area during both 2004 and 2005. Young of the year frogs had much more time to grow before the onset of cooler late fall temperatures than other populations in the Sierra Nevada and North Coast Ranges after transformation. Foothill yellow-legged frogs typically transform during late summer and early fall in populations further north and at higher elevations. Foothill yellow-legged frogs can reach reproductive size as yearlings on upper Coyote Creek. Egg mass size, timing of oviposition and smaller observed sizes of frogs at the breeding area late during the 2005 breeding season suggests yearling frogs contributed to breeding. However, this may not be the case during years of successive wet and cool springtime conditions, particularly if breeding is delayed and/or the onset of winter conditions comes early. This would shorten the length of time young of the year frogs could grow and therefore decrease the number of yearling frogs contributing to breeding.

Low recruitment to adulthood, due to very high spring flows and consequent egg mass scour and/or tadpole mortality should be detectable two years later. I did not collect data on young of the year during 2005, but I observed no foothill yellow-legged tadpoles after

July 1. Growth was likely to be similar to 2004, despite the significant differences in the magnitudes of stream flow between 2004 and 2005. Water temperatures exceeded 18°C by mid-May during 2005. Relatively warm water temperatures and high food availability earlier in the year for rearing tadpoles and transformed young of the year frogs likely explain the observed growth differences between this population and the more studied populations of the Sierra Nevada and North Coast Ranges. Foothill yellow-legged frogs in watersheds further south with breeding populations experiencing relatively warm water temperatures and high food availability earlier in the year, likely exhibit similar growth characteristics as Coyote Creek. For example, I observed hundreds of juvenile frogs on approximately one half of a mile stretch of Clear Creek near the confluence with the San Benito River in San Benito County during September 2005 that were clearly close to 40 mm SVL. Clear Creek is perennial with near zero canopy coverage and very warm spring through fall water temperatures. I took a measurement in late September 2005 of 26°C at the most downstream end of the perennial part of the stream. Food availability is likely to be relatively high for a relatively longer period during the year in this watershed.

Mesohabitat Preference

Females and males preferred pool mesohabitats on both the mainstem and Dexter Creek. However, females showed a strong preference for flatwater (runs) mesohabitats on the mainstem. Both the upper and lower reaches had one step run sequence that was open canopied with boulder/cobble dominated substrate with short turbulent sections with heavy algal growth. These two runs were perennial and heavily used by large adult females as their resident habitat. Females and males preferred boulder dominated

mesohabitats and did not use those dominated by sand or bedrock on both the mainstem and Dexter Creek. Males used gravel and cobble dominated mesohabitats more than females on the mainstem and gravel dominated mesohabitats more than females on Dexter Creek. Females used shadier mesohabitats with slightly less depth than males on the mainstem. However, females occupied mesohabitats with greater escape cover complexity on the mainstem than males. Mesohabitat use and preferences were similar between the sexes in regards to canopy and escape cover complexity on Dexter Creek. Females used deeper pools on average than males.

In general, females established resident habitat sooner after breeding than males. As a consequence, they chose the best quality habitat available. Competitive interactions between adult females and males likely favored larger females and may have allowed for females to maintain residence within the highest quality habitats after the arrival of males from the breeding sites. This may explain a reason why males tended to use mesohabitats that possessed less complex escape cover. There seems to be a selective pressure for mesohabitats with the most complex cover. Future studies that investigate microhabitat use and preference may give a better understanding of mesohabitat use and preference. For example, investigating when and where sunlight hits particular parts of mesohabitats, escape cover, substrate, food availability etc. and their utilization by frogs would be useful. Biotelemetry would be the most effective mode of investigation of specific microhabitat use and preferences as well as frog activity on both spatial and temporal levels.

Predators

Moyle (1973) suggested predation could take a relatively higher toll on fragmented foothill yellow-legged frog populations that remain on tributaries of Sierra Nevada watersheds. Many of these tributaries have non-native, highly predacious and aggressive green sunfish (*Lepomis cyanellus*) residing in them. By contrast, tributaries within the upper Coyote Creek study area have no introduced predators and relatively few native diurnal predators in comparison with the mainstem of Coyote Creek. There were far fewer snakes and no birds observed on Dexter Creek. In addition, the only potential ranaid predator observed were California red-legged frogs, which mainly consisted of young of the year frogs that presumably migrated downstream from breeding sites (primarily livestock ponds) further upstream on the watershed. Adult California red-legged frogs that reside within the tributaries likely do not pose a threat to adult mature adult foothill yellow-legged frogs, mainly due to their largely nocturnal behavior. Also, mature adult female foothill yellow-legged frogs are too large for even the largest California red-legged frogs to ingest. I have observed large female adult foothill yellow-legged and California red-legged frogs basking less than two feet away from each other on many occasions. In short, the lack of diurnal predators on the tributaries within the study area contributes to their value as a refuge for adult foothill yellow-legged frogs.

Observed potential diurnal predators on the mainstem of Coyote Creek outnumbered those observed on Dexter Creek by greater than an order of magnitude. The principal non-native predators observed on the mainstem were American bullfrogs. A small number of Centrarchids (largemouth bass and bluegill) were observed during spring

2005. The majority of these fish were juveniles less than 100 mm. These were likely washed down with high flows from local livestock ponds. The ephemeral nature of most of the upper Coyote Creek watershed does not favor the establishment of largemouth bass or bluegill populations. Their limited numbers and unfavorable physical habitat conditions on the upper Coyote Creek watershed greatly diminish their impact as predators. Some adult bullfrogs seem to be seasonal spring migrants from Coyote Reservoir. They were observed with greater frequency during spring 2004 and 2005 with closer proximity to the reservoir. However, adult bullfrogs were seldom seen after Coyote Creek dried back in early summer as tadpoles transformed and adults migrated back to their resident habitats. A small number of bullfrog tadpoles were washed down from livestock ponds from the heavy rains and consequent high flows of winter-spring 2005. Few bullfrog tadpoles transformed into frogs. Most of the habitats they were trapped in dried up before they could transform. In addition, perennial habitats had adult California red-legged frogs that likely took a heavy toll on tadpoles and juveniles. No foothill yellow-legged frogs were found in any of the several bullfrog stomachs I checked on the lower reach over the course of the study. However, adult bullfrogs often had adult breeding Pacific chorus frogs, California roach and juvenile Sacramento suckers in their stomachs. On one occasion, I found a hatchling western pond turtle in an adult bullfrog stomach on the lower reach during May 2005.

Small numbers of American bullfrogs and Centrarchid fish have the potential to impact foothill yellow-legged frogs, even though I could not detect an effect. The extra pressure these introduced predators put on the population may have a long term negative

impact. These potential impacts may be facilitated during years when tadpole and adult recruitment is low due to severe late season storms or prolonged droughts. Also, foothill yellow-legged frogs have no evolutionary experience coping with these non-native predators.

Santa Cruz garter snakes (a subspecies of aquatic garter snake) were by far the most detectable native predator. They were distributed throughout the mainstem and active at all times when foothill yellow-legged frogs were. Many previous studies have recorded aquatic garters as the most commonly encountered predator where foothill yellow-legged frogs reside (Nussbaum 1983, Jennings and Hayes 1988, Lind and Welsh 1994).

Common mergansers accounted for one fifth of the predator sightings. However, their relative impact as predators was likely quite high in habitats they hunted. I found tadpoles had been decimated on specific amphibian breeding habitats mostly in the middle reach (no foothill yellow-legged frog breeding occurred there) by a female common merganser and her six chicks. Surveys conducted on habitats prior to their detection yielded many thousands of observations of western toad, pacific treefrog and foothill yellow-legged frog tadpoles. Tadpole numbers were reduced to near zero after these birds foraged these habitats for a week or so. Their metabolic needs as an endotherm greatly increase the amount of prey consumed relative to the much more common Santa Cruz garter snake.

Illegal Marijuana Cultivation

Illegal marijuana cultivation is a current threat to the foothill yellow-legged frog population on upper Coyote Creek and likely a threat to all aquatic species within the

watershed, which includes western pond turtles and California red-legged frogs. There were marijuana plantations on four tributaries that flow into the mainstem within the study area. I observed foothill yellow-legged frogs on three of these tributaries during the study. The marijuana cultivators constructed small impoundments and lined them with impervious surfaces to minimize water flowing downstream. They used irrigation pipes to transport water directly to the plants. The cultivators often poured chemical fertilizers directly into the water on the impoundments. The cultivators invariably denuded the terrestrial habitat adjacent to the streams and terraced the slopes. I observed containers of herbicides and pesticides which would presumably be used to protect the marijuana plants from competitors and pests. All of the activities associated with marijuana cultivation on these headwater streams have a strong potential to harm either the physical habitat or the frogs directly. This is particularly true of the water diversions.

The tributary below Sheep Ridge had both frogs and marijuana gardens on it during 2004 and 2005. I consistently encountered 6 to 13 adult frogs during the VES surveys conducted during the summer of 2004. There was one impoundment and two gardens that year. The cultivators expanded during 2005 to three impoundments and seven gardens totaling 6,500 plants. The maximum number of frogs I observed on this tributary during 2005 VES survey was four. The frogs had less water available to them, even though 2005 had much more runoff than 2004. Also, more adult males were able to move into the adjacent tributary Dexter Creek during 2005 in comparison to 2004. These facts are strong circumstantial evidence that there is a clear cause and effect from marijuana cultivation on this tributary and a decline in observed frogs. Other tributaries

utilized for illegal marijuana gardens on this watershed are likely to exhibit the same effect on foothill yellow-legged frog abundance.

There has been an explosive increase of massive illegal marijuana grows in California in the past fifteen years. Drug trafficking organizations from Mexico are primarily responsible for this trend. They utilize tributaries and headwaters which are occupied by remnant populations of sensitive aquatic species such as foothill yellow-legged frogs or those with the potential to support these animals. Small foothill yellow-legged frog populations that have been fragmented and isolated by impoundments created for public uses such as drinking water and hydroelectric power are likely to be susceptible to these illegal marijuana gardens.

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