Secondary Identification and /or Statement of Cooperation

MCBCP Arroyo Toad Monitoring Program:

3-Year Trend Analyses for 2003- 2005

By Cheryl S. Brehme, Sara L. Schuster, Carlton J. Rochester, Stacie A. Hathaway, and Robert N. Fisher

Data Summary

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U.S. Geological Survey

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Dirk Kempthorne, Secretary

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Abstract

In 2003, we implemented a new monitoring program for the endangered arroyo toad (*Bufo californicus*) on Marine Corps Base Camp Pendleton (MCBCP). To address the problems associated with large variations in adult toad activity, we employed a spatial and temporal monitoring approach that tracks the presence of arroyo toad breeding populations by documenting the presence of eggs and larvae. Sites were surveyed up to four times per year to calculate and account for imperfect detection probabilities. We also continued night surveys for adult toads from the monitoring program implemented by Dan Holland in 1996. This report details the results and analyses of the first three years of the spatial monitoring program and a decade of adult count transects.

During this study, three years of highly variable rainfall had large impacts on arroyo toad breeding and breeding habitat. After a normal rainfall year in 2003, minimal rainfall in 2004 resulted in the complete lack of breeding and recruitment within the San Mateo and San Onofre watersheds, which were largely or completely dry. In 2005, twice the normal rainfall created huge surges in all watersheds. Scouring of stream and river channels substantially reduced aquatic vegetative cover and washed away portions of adjacent banks and floodplains.

In tracking both the proportion of area with surface water and the proportion of wet area occupied by breeding toads, we found that even though surface water availability was highly variable (44-95%), the overall extant of breeding toads in wetted areas was relatively stable (77-95%) with no significant change over the three year period. The night survey count data from 1996 to present also shows that arroyo toad activity has had extremely high annual variability (ranging +/- 44% of mean), but has been relatively stable over the last decade.

We found the probability of detecting arroyo toad larvae was positively associated with low flow shallow water and negatively associated with non-native species. These two variables were correlated with one another. During the arroyo toad breeding season, non-native species were associated with deep

and faster flowing water. Since the amount of low flow shallow water was highly variable within each season, this factor was predictive of detecting tadpoles on a given survey, but not of annual occupancy.

For annual occupancy and adult counts, we found compelling evidence that arroyo toad dynamics differ among the watersheds according to hydroperiodicity. Arroyo toad counts for both the ephemeral San Onofre and San Mateo watersheds are positively correlated with the amount of seasonal rainfall. This rainfall relationship was not present in the predictably seasonal Santa Margarita River watershed where arroyo toad dynamics appear to have been largely driven by non-native species. Two equally probable PAO models indicated that the most significant predictors of arroyo toad presence were the absence of crayfish and/or low numbers of non-native species. In the first model, the odds that arroyo toads occupied a site were 11.6 times lower when crayfish were present. In the second model, the odds that arroyo toads occupied a site ere 2.9 times lower when any of the following types of aquatic non-natives were observed; crayfish, bullfrog, mosquitofish, and large non-native predatory fish. This effect was cumulative, so that we were 70 times less likely to find arroyo toad larvae at a site containing all four non-native types.

We expect the effects of urbanization, occurring largely outside the base, may be a primary threat to the arroyo toad in MCB Camp Pendleton. The increased impervious surface area results in altered runoff patterns that can change ephemeral systems to perennial systems and create deeper entrenched channels with faster water flow. This may result in reduced availability of shallow pools required for arroyo toad breeding, as well as support the successful colonization of many aquatic non-native predators that require permanent or near permanent water. We expect these effects to be particularly relevant for the Santa Margarita watershed and Cristianitos sub-watershed. We are also concerned about the negative impacts of the proposed south-foothill toll road on arroyo toad populations in lower San Mateo Creek and Cristianitos Creek. The resulting loss of habitat, road mortality, decreased water quality, and altered hydrology, among other factors, put 10% of the total arroyo toad population on MCB Camp Pendleton at risk of extirpation.

For ongoing species management, we recommend control of non-native aquatic species, especially crayfish and bullfrogs. We also recommend ongoing management of invasive riparian plants, monitoring and analysis of effects of ground water pumping, particularly in lower San Mateo Creek, modeling impacts of off-base development plans on the San Mateo and Santa Margarita watersheds, and continued education and enforcement of steps to minimize the impact of training activities in arroyo toad habitat.

Introduction

The primary mission for Marine Corps Base Camp Pendleton (MCBCP) is "to operate an amphibious training Base that promotes the combat readiness of operating forces by providing facilities, services, and support responsive to the needs of Marines, Sailors, and their families" (MCB Camp Pendleton Strategic Plan 2002). In addition, MCBCP has committed to fulfill stewardship and regulatory requirements for the natural resources on base. This includes monitoring and management for the endangered arroyo toad as described in the MCBCP Integrated Natural Resources Management Plan (October 2001). The U.S. Geological Survey (USGS) was contracted to develop a science based monitoring program for the arroyo toad on MCBCP in 2002 (Atkinson *et al.* 2003) and implemented this monitoring program in 2003. In this report, we analyze trends in arroyo toad occupancy, breeding, and adult activity from 2003 through 2005. We also analyze how these trends relate to environmental conditions and other variables within and among years.

The Arroyo Toad

The arroyo southwestern toad (*Bufo californicus*), hereafter referred to as the arroyo toad, is a specialized amphibian that is endemic to the coastal plain and mountains of central and southern California and northwestern Baja (Jennings and Hayes 1994). It primarily inhabits low gradient streams and rivers that are composed of sandy soils and contain sandy streamside terraces (Sweet 1992, 1993, Barto 1999). Reproduction is dependent upon the availability of shallow, still, or low flow pools in which breeding, egg laying, and larval development occur. These habitat requirements are largely dependent upon natural hydrological cycles and scouring events (USFWS 1999, Madden-Smith *et al.* 2003).

Breeding and larval development within MCB Camp Pendleton typically occur between March and July (Holland *et al.* 2001), depending upon weather conditions. Females produce a single egg clutch each year. Upon fertilization, arroyo toad larvae (tadpoles) emerge in 12 to 20 days and persist in breeding pools 65 to 85 more days. Newly metamorphosed toads may remain by the breeding pools for a few weeks to several months before dispersing to upland habitat to over-winter. As with most amphibians, the survivorship of developmental stages has been reported to be very low (Sweet 1992). The lifespan of the toads is not known, but thought to be approximately five to six years (Sweet 1992, 1993, R. Fisher personal communication).

Currently, the arroyo toad is known to only occupy an estimated 25% of its previous habitat within the United States (Jennings and Hayes 1994). The decline of the arroyo toad has been largely attributed to extensive habitat loss, human modifications to water flow regimes, and the introduction of non-native predators. It was listed by the U. S. Fish and Wildlife Service (USFWS) as endangered in December of 1994. A Recovery Plan for the arroyo toad was then published in 1999 (USFWS).

Study Site

Marine Corps Base Camp Pendleton (MCBCP) is located on approximately 125,000 acres, within the physiographic province of California known as the Peninsular Range. The landscape is characterized by a narrow, sandy shoreline, seaside cliffs, coastal plains, low hills, canyons, and mountains that rise to elevations of over 5,900 feet. Habitats include oak woodlands, coastal sage scrub, native and non-native grasslands, coastal dunes, riparian forest/woodland/scrub, as well as wetlands. MCBCP is bordered by the cities of San Clemente, Oceanside, and Fallbrook to the northwest, southeast, and east, while the Cleveland National Forest and the Pacific Ocean border the northern and western portions. To date, the base is largely undeveloped and encompasses the largest remaining expanse of undeveloped coastline and coastal habitat in southern California. Many species that were once common throughout the Peninsular Range now find their refuge within the borders of MCBCP. This is true for the arroyo toad, which populates three of MCBCP's major watersheds: 1) Santa Margarita, 2) San Onofre, and 3) San Mateo. These represent three of the 22 currently occupied watersheds among Monterey, San Luis Obispo, Santa Barbara, Ventura, Los Angeles, Orange, Riverside, San Bernardino, and San Diego Counties and support the only known remaining coastal populations of the arroyo toad in the United States (USFWS 1999).

MCB Camp Pendleton has a Mediterranean climate with relatively warm, dry summers and mild winters. The rainy season typically falls between October and April, with the most rainfall occurring in January, February and March. The amount of yearly rainfall averages 274 mm (10.8 inches), but is highly variable among years largely due to the influence of the El Niño-Southern Oscillation (ENSO) cycle. The cycle is driven by temperatures in the Pacific Ocean. Warm ocean temperatures create wetter than normal conditions (El Niño) and cool ocean temperatures create drier than normal conditions (La Niña).

The Santa Margarita River is a large fourth order stream that flows through Camp Pendleton, with its watershed covering almost 475,000 acres. There are two main factors expected to affect current and future water flow in this river. First is continued off-base urban development in the upper drainage basin. Increased impermeable surface area in the basin is predicted to increase peak and total water discharge by 50%, resulting in larger and more frequent floods and wetter lowland conditions (Steinitz *et al.* 1996). Second, in March of 2002, a Cooperative Water Resource Management Agreement was made between MCB Camp Pendleton and the Rancho California Water District (RCWD). In order to mitigate the impacts of increased outpumping of underground water in the upper watershed, the RCWD agreed to release a minimum amount of water at the Temecula gorge to simulate flows modeled from 1931-1996. Even in drought years during summer months, this agreement guarantees a minimum flow of 3 cubic feet per second. Due to the size of the watershed and these other factors, this river is expected to have increasingly higher volumes of flow during all years. In years of normal to high rainfall, this change in hydrology may result in significantly lower numbers of suitable breeding pools for the arroyo toad. In contrast, during drought years, this river may provide the only suitable breeding habitat for arroyo toads on MCBCP.

The San Mateo and San Onofre watersheds are relatively small (87,700 and 27,500 acres) and are comprised primarily of second and third order streams. With little runoff, they are typically dry from July to October. In drought years, they can remain dry all year around. According to model simulations, discharge in these basins is predicted to remain the same or decline in the future (Steinitz *et al.* 1996). These watersheds may account for most of the breeding and recruitment of arroyo toads at MCBCP in wet or normal rainfall years, but have little or no recruitment in periods of drought.

Within MCBCP, specific threats to arroyo toad populations may include:

1. Alteration of natural hydrology, increased siltation, and decreased water quality due to increased upstream development in urban areas (e.g., Fallbrook, San Clemente, Murrietta, Temecula) and within MCBCP (south-foothill toll road). These threats are particularly imminent for the San Mateo watershed (Cristianitos Creek) and the Santa Margarita River (Steinitz *et al.* 1996).

2. Potential alteration of hydrology and lack of surface water from excessive groundwater pumping for agriculture and human needs, particularly in the lower San Mateo watershed (per Holland *et al.* 2001).

3. Loss of habitat due to excessive exotic vegetation (e.g. Giant Reed (*Arundo donax),* Tamarisk *(Tamarix sp.)*, non-native grasses (e.g. *Bromus sp*., *Avena sp.)* which can hinder animal movement and/or stabilize stream banks.

4. Excessive predation by exotic predators (e.g. bullfrogs (*Rana catesbeiana)*, crayfish (*Procambarus sp.*)).

5. Loss of foraging or breeding habitat due to potential on base development, toll road development, or intense training activities.

6. Direct (crushing) and indirect (siltation, soil compaction) mortality due to training activities that occur during the breeding season.

Population Monitoring

In order to census populations of the arroyo toad, a monitoring program was first implemented on MCBCP from 1996 to 2000 (Holland *et al.* 2001). Eight 1 km long transects were established on the three occupied watersheds. Night surveys for juvenile, sub-adult, and adult toads were conducted an average of four times per year on these transects. Mean and median survey counts were used to look for trends in arroyo toad populations, however, the large night-to-night variation made it difficult to assess temporal trends in population size. To better assess population sizes, a capture-recapture program was implemented. Passive integrated transponders (PIT tags) were used to individually mark the animals (Holland *et al.* 2001). Unfortunately, after three years of effort, the overall recapture rate (including multiple recaptures of the same individual) was too low (20.8%) to perform any meaningful abundance analysis, as the population estimate variances were too large. In order to collect enough data to narrow these large variances, a more intense monitoring program would need to be performed.

In order to better track trends in arroyo toad populations on MCBCP, a spatial and temporal monitoring approach was designed (Atkinson *et al.* 2003). The log-linear modeling program, PRESENCE, is used to calculate annual estimates of proportion area occupied (PAO) by the arroyo toad, as well as the probabilities of detection, colonization, and extinction over time (MacKenzie *et al.* 2002, 2003). Because the probability of detecting a species on any single survey is typically not perfect, site occupancy can be underestimated. In this model, site occupancy is determined after correcting for a detection probability calculated from data obtained on multiple visits. Percent site occupancy can then be used as a metric to monitor long-term trends in populations. This model also allows for analysis of site and survey specific covariates. These covariates can be environmental and habitat variables that vary (survey specific) or do not vary (site specific) with each survey visit. These include variables that may affect detection probabilities, such as weather and water variables, and others that are directly related to land use and management activities, such as the presence of non-native plant and aquatic species, military activities on site, water quality, and human impacts to the hydrological regime. Thus, impacts of these activities can be assessed over time to make more informed management decisions on base. This approach is currently being implemented across the country as part of the U.S.G.S. Amphibian Research and Monitoring Initiative (http://armi.usgs.gov). This program does not directly track trends in population abundance.

A workshop to devise the arroyo toad monitoring protocol reported here was conducted on August 27, 2002 with arroyo toad experts from the USGS, U.S. Fish and Wildlife Service, MCBCP, U.S. Forest Service, California Department of Fish and Game, and the Universities of California, at San Diego and Davis. The discussion points, consensus, and complete theoretical protocol are detailed in Atkinson *et al.* (2003). In summary, suitable habitat within the three major watersheds on MCBCP (Santa Margarita, San Mateo, and San Onofre) were divided into 60 linear 1.5 km segments ("blocks") which were then subdivided into six linear 250m survey segments ("sites") (Table 1, Figure 1). The average slope of a survey site is 1.9% with a range of 0 to 12%. One randomly chosen site within each block is surveyed yearly (permanent). The other sites are surveyed on a five-year rotating basis. This way, at least 60 sites are surveyed yearly while the entire watershed is surveyed every five years. An important protocol decision was to survey for egg clutches and tadpoles during the breeding season rather than to survey for adult toads. This increases probability of detection as, under normal conditions, eggs and tadpoles are easily observable during the day for up to three months in time. In 2003, a supplemental study confirmed that tadpoles were twice more likely to be detected than adults (Brehme *et al.* 2003). In addition, the presence of eggs and/or tadpoles directly indicates the nearby presence of reproductive adults.

This protocol requires the presence of water. Thus, in drought years, some areas may not be surveyed. Even with sufficient rains, breeding may not occur if the rains are unseasonably late. Sweet (1992) attributed the lack of arroyo toad breeding in the Los Padres National Forest in 1990 to cool dry weather in the winter and spring of that year. It was hypothesized that the dry period delayed foraging and vitallogenesis (egg formation). As a result, most female toads apparently did not have mature clutches until after most males had ceased calling. Thus, the percent site occupied model is limited to breeding activity only. It should be noted that successful recruitment cannot be confirmed with this survey method.

In order to compare this new approach and provide continuity with the 1996-2000 monitoring efforts, eight blocks were designed to overlay the same transects where count data would also be collected (Figure 2). These blocks are surveyed at night for arroyo toad adults three times throughout the breeding season. The night surveys were designed to compare adult counts to the 1996-2000 data and to gather information on individual toads that were originally PIT tagged from 1998-2000 (Holland *et al.* 2001).

TABLE 1. ARROYO TOAD OCCUPANCY MONITORING: LOCATION AND NUMBERING OF SURVEY BLOCKS AND SITES

Watershed	River/Creek[1]	Length of potential habitat (km)	No. blocks (1.5 km each)	No. sites[2] (250 m each)	Designated[3] block/site names
San Mateo		32.3	21.5	129.0	39A-60F
	Lower San Mateo Creek	4.5	3.0	18.0	39A-41F
	Upper San Mateo Creek	12.8	8.5	51.0	42A-50C
	Cristianitos Creek	4.2	2.8	17.0	51A-53E
	Talega Creek	10.8	7.2	43.0	53F-60F
San Onofre		18.0	12.0	72.0	27A-38F
	Lower San Onofre Creek	9.0	6.0	36.0	27A-32F
	Upper San Onofre Creek	4.5	3.0	18.0	33A-35F
	South Fork San Onofre Creek	1.2	0.8	5.0	36A-36E
	Jardine Canyon Creek	3.3	2.2	13.0	36F, 37A-38F
Santa Margarita		39.0	26.0	155.9	1A-26F
	Lower Santa Margarita River	15.0	10.0	60.0	1A-10F
	Upper Santa Margarita River	14.5	9.7	58.0	11A-20E (-12F)
	Deluz Creek	7.2	4.8	29.0	12F, 21A-25D
	Roblar Creek	2.3	1.5	9.0	26A-26F, 20F, 25E, 25F
Total		89.3	59.5	356.9	1A-60F

[1]"upper" and "lower" designations are arbitrary and primarily based upon location within MCBCP, stream order, and/or vegetation characteristics.

[2] six sites are designated within each block. They are labelled with the block number followed by the letter A, B, C, D, E, or F.

[3] Because not all waterways of the defined potential breeding habitat were perfectly divisible into a whole number of 1.5 km blocks, some blocks were split up between the upper end of creeks within the same watershed.

FIGURE 1. LOCATION OF SURVEY BLOCKS AND SITES FOR ARROYO TOAD EGGS AND LARVAE WITHIN MCB CAMP PENDLETON

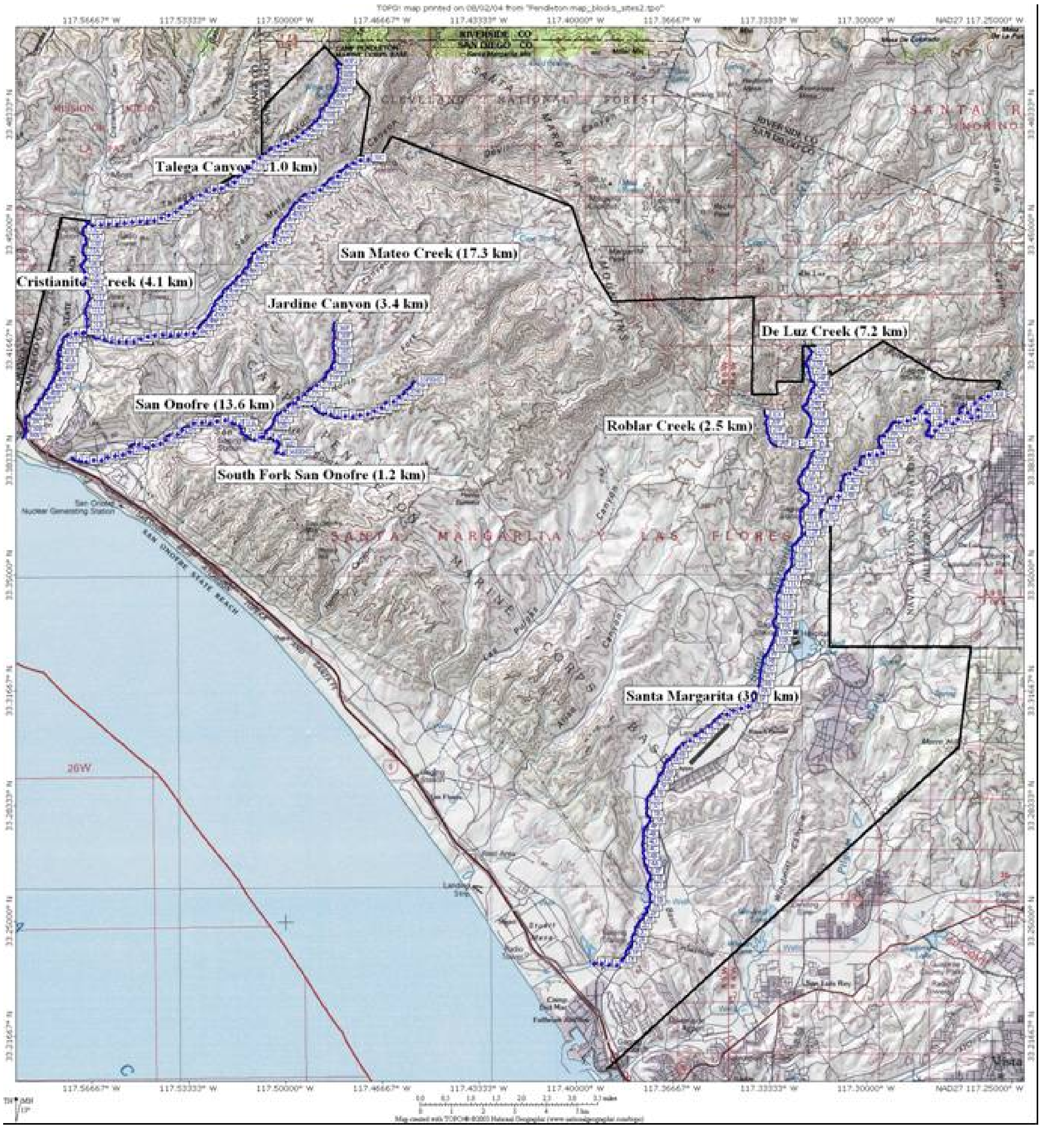
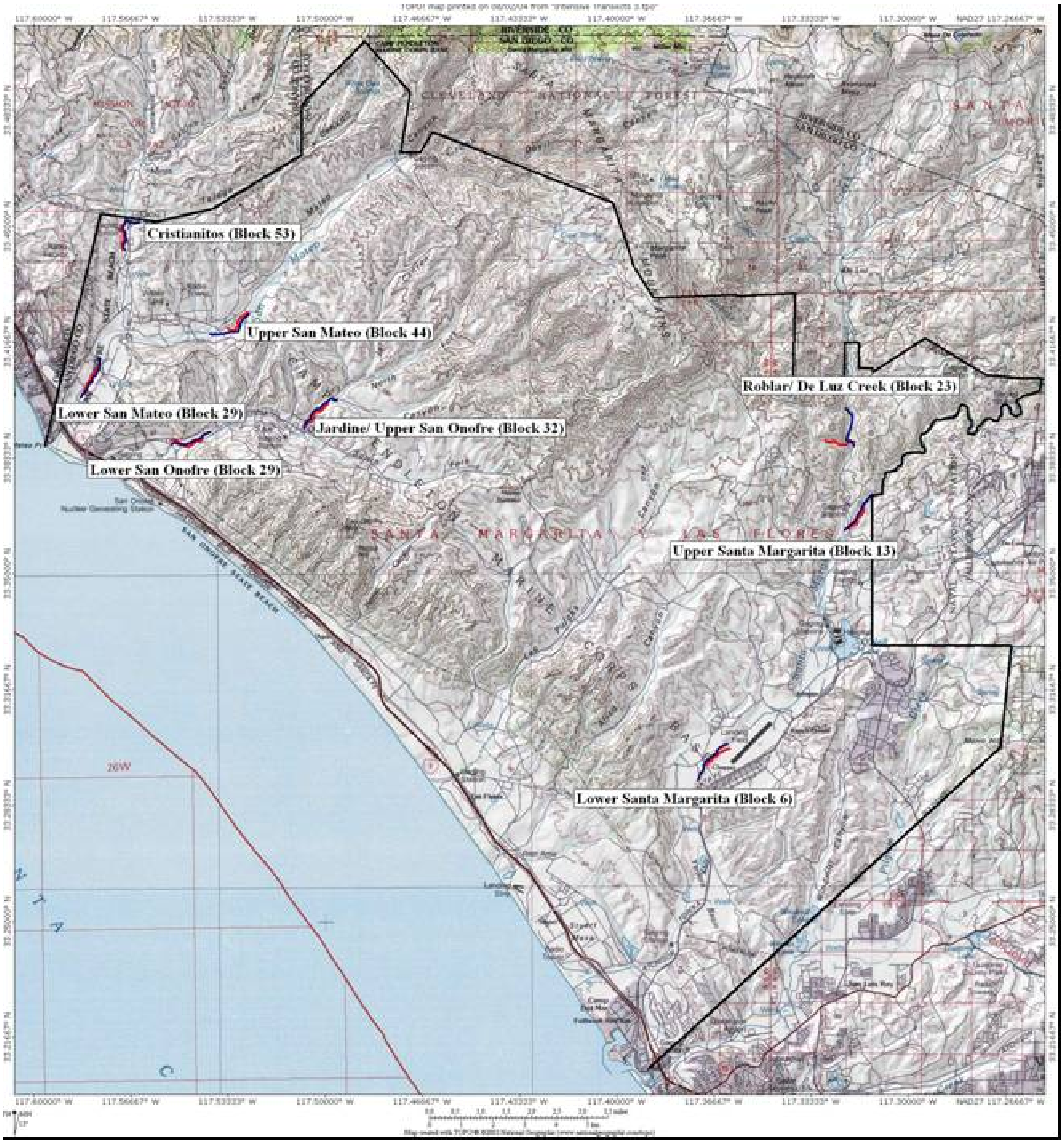


FIGURE 2. LOCATION OF NIGHT SURVEY BLOCKS FOR JUVENILE, SUB-ADULT, AND ADULT ARROYO TOADS WITHIN MCB CAMP PENDLETON



Red lines = 1996-2000 survey blocks

Blue lines= 2003-2005 survey blocks

Methods

Survey Methods

We describe three survey methods conducted for arroyo toad monitoring from 2003 through 2005, 1) initiation of breeding surveys, 2) day surveys for presence of arroyo toad larvae, and 3) night count surveys for juvenile, sub-adult, and adult arroyo toads. General methods and changes to the day protocol implemented in 2004 are highlighted in this section. Detailed field protocols for both the day and night surveys are included as Appendices 1 and 2. Subsequent data analyses, results and discussion sections will also be presented individually for these three survey types.

Initiation of Breeding

The purpose of this survey technique is to determine when arroyo toad breeding has begun. Once breeding has been detected, we can then schedule subsequent day surveys for egg clutches and larvae at the appropriate time.

The advertisement call of the arroyo toad is a unique clear, whistling trill lasting between four and nine seconds (Sweet 1992). Arroyo toad females lay eggs at the males calling site in linear envelopes ranging from 10 to 35 feet in length and contain approximately 5000 eggs (Sweet 1992). The egg clutches are very similar to those of the western toad, *Bufo boreas*. However, the western toad primarily lays its eggs in deeper water (13-29 cm) on submerged vegetation. Arroyo toad eggs are usually laid in shallow water (1.5-14 cm) away from any vegetation. Due to this microhabitat association, Sweet (1992) suggests that eggs can be safely identified to species by microhabitat alone. However, the species determination cannot be absolute until confirmed by subsequent identification of larvae. For the purposes of this survey, breeding is confirmed after detection of calling males followed by observation of egg clutches in pools characteristic of the arroyo toad.

In February to early March, typically when mean temperatures start to warm to approximately 15°C (60°F), we start monitoring for breeding across the base. Every few weeks, we check each watershed for positive breeding conditions (presence of low flow shallow water along river/creek edges and/or pooling water within the channels) and the presence of egg masses. We also begin our night count surveys during this time and actively listen for calling males. Once calling arroyo toad(s) are documented, we continue to monitor the base for egg strings until breeding is confirmed.

Presence Surveys

Once initiation of breeding is confirmed, day surveys are scheduled at all wetted permanent and year specific sites (5-yr rotation, Atkinson, *et al.* 2003). These surveys are conducted in order to document the presence of arroyo toad eggs and/or larvae, which directly indicates the presence of breeding adults. One to four surveys per site per year were conducted. The number of surveys depended upon site designation and whether arroyo toad eggs or larvae were detected on the first visit (Table 2). In 2004, we implemented some minor changes in the distribution and number of repeat surveys per site in an attempt to increase the precision of parameter estimates and our ability to fit logistic models to the data (Brehme *et al.* 2004).

TABLE 2. PRESENCE SURVEYS: SURVEY FREQUENCY IN 2003 VS. 2004-5

Year(s)	Number of Sites	Site Type*	Frequency (surveys per year)	Notes
2003	16	permanent & 5-yr rotation (intensive)	4	2 sites within each of 8 blocks (coupled)
	104	permanent & 5-yr rotation	1-2	2nd survey only if not detected on first
2004-5	16	permanent (intensive)	4	not coupled- 8 new sites randomly chosen
	44	permanent	2	
	60	5-yr rotation	1-2	2nd survey only if not detected on first

* "permanent" = surveyed yearly, "5-year rotation" = surveyed every 5 years

We attempted to survey all habitat in a spatially and temporally stratified order to avoid issues of autocorrelation. However, because breeding (i.e. water flow) conditions are not uniform across the base, there may be some temporal order to the surveys among watercourses. Therefore, initial surveys were scheduled in the order of past breeding patterns. These patterns largely correspond to hydroperiod length, from the shortest (lower San Onofre, Talega, Cristianitos, and Roblar Creeks) to the longest (Santa Margarita River). Temporal trends in breeding patterns across the base are further discussed in the Results section, Arroyo Toad: Initiation of Breeding. Repeat surveys were conducted from one week to one month after the initial survey and closer to the latter if tadpoles were not detected on the first survey.

All surveys were conducted with two field biologists trained in identification of arroyo toad eggs and larvae. For each survey site, biologists slowly walked upstream and carefully scanned the waters for arroyo toad eggs and larvae. Upon finding the first egg clutch or larvae, presence was recorded. The pool containing the egg clutch or larvae was characterized. Subsequent arroyo toad eggs and larvae encountered along the site length were not recorded, as presence was already established. While walking the site length, all other aquatic species observed were also recorded. Upon completing the site, if no arroyo toad eggs or tadpoles were found, the biologists went back to what represented the most likely potential arroyo toad breeding pool within the site to search for an additional 10 minutes. If no arroyo toad eggs or larvae were found, the unoccupied pool was characterized. There are also several other landscape and water attributes that were recorded at each site (Table 3). These were updated in 2004 in an attempt to better characterize the channel and water flow conditions for use with a wider range of species and analyses.

A sub-sample of arroyo toad larvae and adults were digitally photographed as vouchers. A sub-sample of other nonsensitive aquatic species that were incidentally encountered were also photographed and/or preserved in 95% ethanol as voucher specimens in accordance with CDFG Permit SC-4186 and accompanying USGS/USFS Memorandum of Understanding. All vouchers are stored at the USGS/WERC/BRD specimen repository in the San Diego Field Station. The field protocol is provided in Appendix 2.

Night Count Surveys

We conducted three surveys per year on each of the eight 1-km transects to count juvenile, sub-adult, and adult arroyo toads. The transects were first surveyed in early February to early March, when nighttime temperatures started to warm to approximately 15°C (60°F), then resurveyed each successive month. All surveys were conducted with two field biologists trained in identification of arroyo toad adults. At least 30 minutes after sunset, survey teams slowly walked the stream and streamside floodplains or terraces using Kohler© headlamps or flashlights to search for and count adult arroyo toads. All toads found on land were measured (snout to urostyle length) and scanned for PIT tags using an Avid Mini Tracker©. The field protocol is provided in Appendix 3.

TABLE 3. PRESENCE SURVEYS: COVARIATES RECORDED IN 2003 VS. 2004-5

2003	2004-5
Landscape attributes	
Presence of Sand (>10m)	Proportion of channel with sand
Presence of Sandy terraces (>10m)	Proportion of 2nd level (flood plain/ terrace/ or upland) with sand
Presence of channel braiding (>10m)	*
Habitat Quality Rating (based on above variables)	*
*	Entrenchment ratio (bank width/ flood plain width)
Water conditions	
*	Water temperature
*	Water depth (at thalweg)
*	Wetted channel width
*	Surface water velocity
*	Water chemistry (pH, conductivity, dissolved oxygen)
Vegetation	
Presence of non-native aquatic/ riparian plants (record species)	Presence of non-native aquatic/ riparian plants (record species)
*	Channel vegetation type
*	Percent cover- aquatic submerged/floating veg
*	Percent cover- aquatic emergent vegetation
*	Percent cover- algal mat
*	2nd level: Presence of floodplain/terrace or upland
*	Vegetation type
*	Percent cover- herb layer
*	Percent cover- shrub layer
*	Percent cover- tree layer
Pool characterization	
Percent cover- sand	Percent cover- sand
*	Percent aquatic submerged/floating vegetation
*	Percent aquatic emergent vegetation
Percent overhead cover	Percent overhead cover
Water temperature	Water temperature
Pool depth	Pool depth
Pool turbidity	Pool turbidity
Other	
Presence of other native & non-native aquatic animals (record species)	Presence of other native & non-native aquatic animals (record species)

* no data taken

Data Analyses

We analyzed arroyo toad breeding presence data from the day surveys using the loglinear modeling program PRESENCE (MacKenzie *et al.* 2002, 2003). During the surveys, we also collected a large amount of environmental, landscape, and water covariate data. For data analyses, however, it is important to carefully formulate a priori hypotheses on what factors may affect the detection probability, occupancy, and/or colonization and extinction probability of the species of interest. This prevents issues with ‘data dredging’ such as high probabilities of Type II errors that may lead to incorrect conclusions and inferences (Burnham and Anderson 2002). In order to understand multivariate patterns and to reduce our number of possible covariates, we first ran Pearson and Spearman rank tests for all covariates to determine which were correlated. If two or more covariates were highly correlated (i.e. Bonferroni adjusted $p<0.05$ and $r>0.25$), we chose the single variable that we thought was most likely to directly affect arroyo toad occupancy and/or detectability. Before running any models, we then generated our a priori hypotheses from our reduced set of covariates (Table 4).

In summary, our a priori expectation was that the probability of detecting arroyo toad eggs and/or tadpoles would be greater when the water conditions were favorable for breeding (low flow-shallow water index). We expected they would be harder to detect when there was a large amount of aquatic vegetation (aquatic vegetation index) and in the presence of known predators and/or competitors (crayfish, mosquitofish, large predatory fish, bullfrogs), although this relationship could be temporarily positive as it is expected that predators are attracted to areas of high prey densities. We hypothesized that several factors would affect probabilities of occupancy and colonization. Arroyo toads are known to prefer wide channels (entrenchment ratio) with high sand cover (sand cover index), low vegetative cover (aquatic vegetation index) and open floodplains or terraces (flood plain/terrace vegetative cover index). They may require a minimum hydroperiod to breed successfully, which may influence their continued occupancy or colonization in future years (hydroperiod; current year, previous year). Conversely, very long hydroperiods may increase the numbers of exotic aquatic species (predators/competitors) and thus have a negative or nonlinear effect. The possibility that detection and colonization/extinction probabilities would vary by year was also tested for all parameters.

We approached model building in a stepwise manner. First, we focused on modeling detection probabilities. Then, we selected the best models from that analysis to use in modeling first year

TABLE 4: A PRIORI PAO MODEL HYPOTHESES

Covariate	Definition	Correlated Variables	Hypothesized Effect
Detection probability/ Activity (ρ)			
Year	Year of survey	n/a	n/a
*Low flow shallow water index	Proportion of site containing low flow shallow water	Channel velocity, discharge, dissolved oxgen (DO_{sat})	Positive
*Aquatic vegetation cover index	Total cover of submergent, emergent, algae mat	Component variables correlated	Negative
Presence of predators and/or competitors (tested individually)	Western toad, crayfish, mosquitofish, bullfrog, non-native species index (sum of last 4 species)	Species data: detected, not detected. Non-native Index is sum of crayfish, mosquitofish, predatory fish, and bullfrog detections.	Negative
Initial Presence/ Absence (Ψ) and Colonization/Extinction (γ, ε)			
Year	Year of survey	n/a	n/a
*Entrenchment ratio	Confinement of channel: flood prone width ÷ bank width (lesser value= more confined)	Flood prone width, bank width	Negative
*Channel sand cover index	Proportion of channel with sand	Flood plain sand cover	Positive
*Aquatic emergent vegetation index	Yearly estimates of total cover from emergent vegetation	Aquatic submergent vegetation index, aquatic cover index	Negative
*Disturbance level index	Level of disturbance from training activities (artillery, troops, heavy equipment)	n/a	Negative
Hydroperiod (current year & previous year)	Hydroperiod (months wet) for water year (July-June)	n/a	Both
Presence of predators and/or competitors (tested individually)	Western toad, crayfish, mosquitofish, bullfrog, non-native species index	see above	Negative

Landscape/Vegetation Index Values (0= 0%, 1= 1-10%, 2= 11-25%, 3= 26-50%, 4= 51-75%, 5= 76-100%)
Disturbance Index Values (0= none, 1= low, 2= high)
* Covariate data collected in 2004 and 2005 only

occupancy, colonization and extinction probabilities. For this, each parameter covariate was tested individually and then together if warranted. We used Akaike's Information Criterion (AIC) and model selection procedures described by Burnham and Anderson (2002) to rank and compare models. Models that showed evidence of overfitting (i.e. no convergence was reached, a variance-covariance matrix was unable to be produced, standard error of a parameter estimate was greater than the parameter estimate) were not evaluated. Since the PRESENCE software is currently not capable of calculating model fit parameters for multi-season data (i.e. dispersion or c-hat) which can be used to calculate adjusted quasi-AIC and standard error values (MacKenzie and Bailey 2004, Darryl MacKenzie pers. comm.), we used the small sample corrected AIC (AIC_c) to compare models:

$$AIC_c = AIC + 2\ (K(K+1)/(n-K-1))$$

where n= sample size and K is the number of parameters in the model. The sample size was set to 60, the number of permanent survey sites, to further increase the weight of the number of parameters, thereby favoring the most parsimonious model. Since there is no model fit parameter (dispersion or c-hat) to adjust standard errors that may be underestimated, the unadjusted values presented should be interpreted with caution.

In 2004, we incorporated the measurement of several water flow and landscape variables that were not part of the survey data in 2003 (see table 3, Atkinson et al 2002, Brehme et al 2004). Analysis of multi-season datasets in PRESENCE requires that covariate values exist for all values of the response variable (arroyo toad detection). Thus, we built two sets of models; one set for all three years of data (2003 to 2005) and a second for the two-year data set (2004 and 2005).

We used multiple linear regression to analyze the night count survey data from 1996-2001 (Holland *et al.* 2001) combined with our 2003 to 2005 data. The dependent variable was counts of arroyo toads for each site survey, which we square root transformed to approximate a normal distribution. We used binary coding to represent the categorical explanatory variables; hydroperiod (ephemeral/ perennial), year, and site, along with quantitative rainfall data. There were not sufficient degrees of freedom to analyze all variables in the same model, so we used a forward selection approach to model building. We validated the final model chosen by our statistical program by exploring models with different subsets of variables and comparing parameter estimates and significance values. We were confident that when the subset variable models gave similar estimates, our final model was a good representation of the data. Analyses were performed using Systat 10 and SPSS 11.0 statistical software.

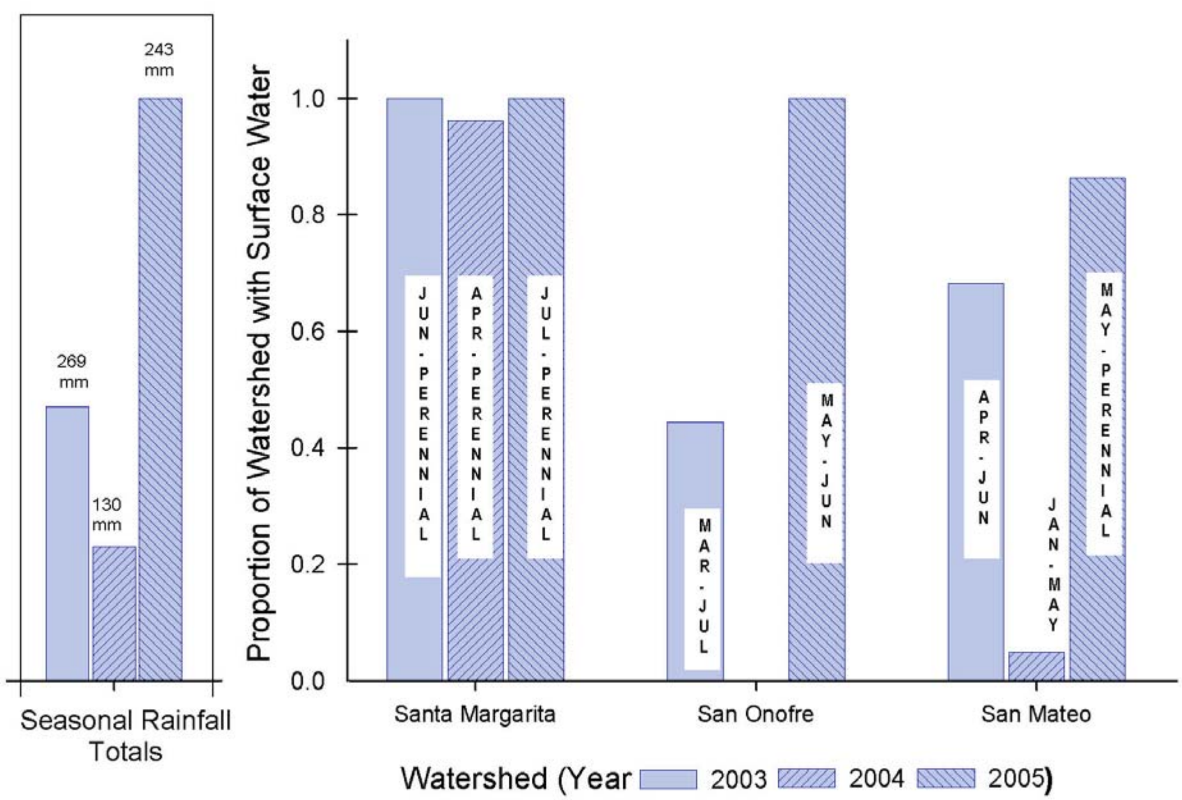
Results

Weather and Watershed Patterns

During the first three years of arroyo toad monitoring, seasonal rainfall totals in San Diego County (October to September) ranged from one-half to twice the historical mean level of 10.8 inches. The rainfall totals were 269, 130, and 572 millimeters (10.6, 5.2, and 22.5 inches) for 2003, 2004, and 2005, respectively. Both 2003 and 2005 had warmer than normal Pacific Ocean temperatures (National Weather Service 2006).

The highly variable rainfall resulted in greatly different hydroperiods within and among the watersheds. The proportion of each watershed that had surface water at the onset of breeding season (March-April) and the range of months when surface water was present are shown in Figure 3. Varying surface water availability directly influences arroyo toad breeding, larval development, and the chance of metamorphoses.

FIGURE 3. PROPORTION OF EACH WATERSHED WITH SURFACE WATER AND MONTHS WITH WATER PRESENT FROM 2003-2005



In addition to presence of surface water, the timing and quantity of rain, along with channel characteristics, affect the frequency, magnitude, and duration of flow events, which in turn affect channel morphology and stream habitat (USEPA 1997, McMahon *et al.* 2003). These measures varied widely among years and among watersheds, with 2005 showing extraordinarily intense stream flashiness and heavy flows (Table 5). All values were calculated from daily USGS water gauge data (*http://waterdata.usgs.gov*). Data was limited to active USGS gauges located at the upper portions of the Santa Margarita River and San Mateo Creek and at the lower portion of San Onofre Creek.

TABLE 5. RAINFALL AND STREAM HYDROLOGY CHARACTERISTICS

	2002-3	2003-4	2004-5
Seasonal Rainfall (mm)	269	130	572
Santa Margarita River (gauge 11044300 -1.3 mi. upstream from MCBCP border)			
frequency (no. of pulses > 100 ft^3/sec)	5	3	13
duration (no. of days > 100 ft^3/sec)	14	5	52
magnitude(maximum discharge ft^3/sec)	2500	662	4000
San Mateo Creek (gauge 11046300 -0.4 mi. downstream from mouth of Devils canyon at MCBCP border)			
frequency (no. of pulses > 100 ft^3/sec)	3	0	9
duration (no. of days > 100 ft^3/sec)	8	0	56
magnitude(maximum discharge ft^3/sec)	816	72	2410
San Onofre Creek (gauge 11046250 -0.3 mi. upstream from mouth)			
frequency (no. of pulses > 100 ft^3/sec)	2	0	3
duration (no. of days > 100 ft^3/sec)	2	0	16
magnitude(maximum discharge ft^3/sec)	341	54	1600

1 ft^3 = 0.0283 m^3

The extraordinary flows in 2005 resulted in major channel scouring throughout the base. Channel measurements taken in the Santa Margarita River in 2004 and 2005 provide evidence that a significant portion of the flood plain was washed away, creating a wider more incised river channel with less vegetative cover. On average, the width of the river channel increased by 55%, from 28 to 43 meters, resulting in a subsequent 50% decrease in floodprone width and corresponding entrenchment ratio (11.7 to 5.6). The emergent vegetation cover also decreased from a median range of 11-25% to 1-10%. As these landscape measurements were added to the protocol in 2004, when San Mateo and San

Onofre watersheds were completely dry, we do not have numerical comparisons for those watersheds between 2004 and 2005. However, photographs taken at the same locations in 2003 and 2005 clearly show major scouring took place in these systems as well. Photographs taken in all three watersheds before and after the 2005 scouring are shown in Figure 4.

FIGURE 4. EFFECTS OF 2005 RAIN EVENTS ON CHANNEL MORPHOLOGY AND VEGETATION

San Mateo Creek 2004 vs. 2005 (Site 44C)

San Onofre Creek 2004 vs. 2005 (Site 32B)

Lower Santa Margarita River 2004 vs. 2005 (Site 6E)

Mid Santa Margarita River 2004 vs. 2005 (Site 12C)

Upper Santa Margarita River 2004 vs. 2005 (Site 18C)

Vegetation

Native and non-native riparian vegetation varied within and among the watersheds (Table 6). Most areas were dominated by mulefat riparian scrub or southwestern willow scrub. Mulefat riparian scrub is dominated by mulefat (*Baccharis salicifolia*) with a lesser component of willow (*Salix* sp.), cottonwood (*Populus fremontii*), and/or sycamore trees (*Platanus racemosa*). This vegetation is often found in the channel and floodplain where it is commonly associated with coarse alluvial soils and subject to regular disturbance events (*i.e.*, episodic flooding, scouring). This vegetation was dominant along the floodplains and terraces of the San Onofre and San Mateo watersheds. If the willow was dominant over mulefat, the vegetation was characterized as southern willow scrub (Zedler *et al.* 1997), which is often found on flood plains and terraces subject to less frequent water inundation or disturbance events. This vegetation was dominant along terraces of Santa Margarita River. In 2003 and 2004, the upper Santa Margarita River also had large amounts of aquatic emergent vegetation in the channel and floodplains, including dense cattails (*Typha latifolia*) and sedges (*Carex* sp.) along the river margins. It appeared that these species had a stabilizing effect on the riverbanks, as they were typically associated with deep narrow portions of the river. These were significantly reduced after the 2005 scouring events (Figure 4).

Of the non-native species recorded, mustard, fennel (*Foeniculum vulgare*), and non-native grasses (*Bromus* sp., *Cynodon dactylon*, and others not identified to species) were the most widespread occurring in all major drainages and watersheds. Giant reed (*Arundo donax*) was significantly reduced due to recent removal efforts; however, new growth is present in scattered patches along parts of the San Onofre and San Mateo watersheds with large contiguous stands recently observed along the lower Santa Margarita River. Similarly, tamarisk was also observed along portions of the San Mateo and Santa Margarita watersheds and appeared to be slightly increasing in densities in 2005. Watercress (*Rorippa nasturtium-aquaticum*), an aquatic emergent plant has also become well established along the Santa Margarita River. Other non-native plants observed included exotic thistle (*Centaurea* sp., *Cirsium* sp., *Cyanara* sp., other), castor bean (*Ricinis communi*s), palm tree (Palmaceae), tree tobacco (*Nicotiana glauca*), hemlock (*Conium sp.*), and periwinkle (*Vinca* sp.). Patch size classes and locations of the most common species among years are presented in Table 6.

TABLE 6. VEGETATION AND NON-NATIVE PLANT OBSERVATIONS

		Watershed- creek/river										
		San Mateo				**San Onofre**			**Santa Margarita**			
	Year	Lower	Upper	Crist-ianitos	Talega	Lower	Upper	Jardine	Lower	Upper	Deluz	Roblar
Vegetation	*Block*	*39-41*	*42-50*	*51-53*	*54-60*	*27-32*	*33-36*	*37-38*	*1-10*	*11-20*	*21-25*	*26*
Dominant Type Riparian/Upland	2003	MRS	MRS	MRS	MRS	MRS	MRS	MRS	SWS	SWS	SWS	SWS
	2004	~~d~~	CSS		~~d~~	~~d~~	~~d~~	~~d~~	SWS	SWS	MRS	~~d~~
	2005	MRS	MRS	MRS	MRS	MRS	MRS	NNG	SWS	SWS	SWS	MRS
Dominant Type Channel	2003	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	2004	~~d~~	MRS		~~d~~	~~d~~	~~d~~	~~d~~	OWC	OWC	OWC	~~d~~
	2005	OWC	OWC	OWC	OWC	OWC	OWC	OWC	OWC	OWC	OWC	OWC
Median Percent Cover in Channel	2003	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	2004	~~d~~	1-10%		~~d~~	~~d~~	~~d~~	~~d~~	11-25%	25%	1-10%	~~d~~
	2005	1-10%	1-10%	1-10%	1-10%	1-10%	1-10%	1-10%	1-10%	1-10%	1-10%	1-10%
Non-native Plants	*Block*	*39-41*	*42-50*	*51-53*	*54-60*	*27-32*	*33-36*	*37-38*	*1-10*	*11-20*	*21-25*	*26*
Giant reed	2003		F	F					S	S		
	2004	~~d~~			~~d~~	~~d~~	~~d~~	~~d~~	L			~~d~~
	2005	F	S		S	F		F	L	S		
Tamarix	2003		S	S					L	F	F	F
	2004	~~d~~			~~d~~	~~d~~	~~d~~	~~d~~	L	F	F	~~d~~
	2005	F	F	L					L	F	S	
Watercress	2003											
	2004	~~d~~			~~d~~	~~d~~	~~d~~	~~d~~	L	L	L	~~d~~
	2005		S				S		L	S	L	
Non-native thistle	2003	F	S	S	S	S		F				
	2004	~~d~~			~~d~~	~~d~~	~~d~~	~~d~~				~~d~~
	2005	F										
Castor bean	2003	F										
	2004	~~d~~			~~d~~	~~d~~	~~d~~	~~d~~		F		~~d~~
	2005	S							S	S		
Fennel	2003	F	F	F	S	L	S	S	L	L	L	S
	2004	~~d~~	F		~~d~~	~~d~~	~~d~~	~~d~~		F	F	~~d~~
	2005	L	S	F	S	F	S	L	L	S	S	F
Mustard	2003	L	L	L	L	L	L	L	L	L	L	L
	2004	~~d~~			~~d~~	~~d~~	~~d~~	~~d~~	L	S	L	~~d~~
	2005	L	L	L	L	L	L	L	L	S	L	S
Tree tobacco	2003											
	2004	~~d~~			~~d~~	~~d~~	~~d~~	~~d~~				~~d~~
	2005		S			F	F			F		
Palm tree	2003											
	2004	~~d~~			~~d~~	~~d~~	~~d~~	~~d~~				~~d~~
	2005					F	F					
Non-native grasses	2003	S	L		L	L	L	L	L	L	L	S
	2004	~~d~~			~~d~~	~~d~~	~~d~~	~~d~~	S	S	S	~~d~~
	2005	L	L	L	L	L	L	L	L	L	L	L

~~d~~ = dry throughout year, day surveys not conducted, n/a = specific data type not collected in 2003

Vegetation Codes: MRS = mulefat riparian scrub, SWS = southern willow scrub, OWC = open water/ channel, CSS = coastal sage scrub, NNG = non-native grassland

Size Classes: F = few plants, S = scattered patches, L = large contiguous stands (largest size class recorded among surveys is presented)

Non-target Aquatic Species

We documented larvae and adults of many non-native aquatic species in MCBCP (Table 7), including bull frog (*Rana catesbeiana*), mosquitofish (*Gambusia affinis*), bullhead catfish (*Ameiurus* sp.), green sunfish (*Lepomis cyanellus*), bass (*Micropterus* sp.), crayfish (*Procambarus clarkii*), Asian clam (*Corbicula fluminea*), and beaver (*Castor canadensis*). All of these species were detected in the Santa Margarita River. Mosquitofish, bullfrog, and green sunfish were also detected in the uppermost portion of San Mateo Creek within MCBCP, which can be perennial in wet years. Mosquitofish were the only non-native species found in Talega and Cristianitos Creeks. No non-native aquatic species were detected in the ephemeral San Onofre watershed or Roblar Creek from 2003 to 2005.

We also documented larvae and adults of several non-target native aquatic species (Table 8). The Pacific tree frog (*Pseudacris regilla*), California tree frog (*Pseudacris cadavarina*), western toad (*Bufo boreas*), and two-striped garter snake (*Thamnophis hammondii*) were the most widespread, occurring in most or all drainages of the three watersheds. We observed arroyo chub (*Gila orcutti*) all three years along the Santa Margarita River and adjacent Deluz Creek.

The California newt (*Taricha torosa*) was largely isolated to Roblar Creek, particularly associated with a perennial plunge pool that exists approximately 750 m from the confluence of Deluz Creek. Detections of this species were variable among years due to the combination of fire and flood events. In 2003, we observed 24 newts at the Roblar pool and creek, including two pairs in amplexus. The Roblar pool completely filled with sediment from post-fire erosion in 2004 and we subsequently found only a single newt in nearby Deluz Creek. In 2005, water scouring recreated the pool and we subsequently observed 37 newts, one newt larvae, and one egg mass at the Roblar pool and creek.

Infrequently, we observed spadefoot toads or larvae along upper San Mateo Creek, Cristianitos Creek, and Jardine Canyon. This species is not included in the table because they are known to primarily live and breed in upland areas, rather than creeks and rivers.

TABLE 7. NON-NATIVE AQUATIC SPECIES OBSERVATIONS

			Watershed- creek/river										
			San Mateo				**San Onofre**			**Santa Margarita**			
Common Name	Scientific Name	Year	Lower	Upper	Crist-ianitos	Talega	Lower	Upper	Jardine	Lower	Upper	Deluz	Roblar
Amphibians		*Block*	*39-41*	*42-50*	*51-53*	*54-60*	*27-32*	*33-36*	*37-38*	*1-10*	*11-20*	*21-25*	*26*
Bullfrog	*Rana catesbiana*	2003	X	X						X	X		
		2004	~~d~~	X		~~d~~	~~d~~	~~d~~	~~d~~	X	X	X	~~d~~
		2005		X						X	X		
Fish													
Mosquitofish	*Gambusia affinis*	2003	X	X	X	X				X	X		
		2004	~~d~~		X	~~d~~	~~d~~	~~d~~	~~d~~	X	X	X	~~d~~
		2005			X					X	X	X	
Bullhead Catfish	*Ameiurus sp.*	2003								X	X		
		2004	~~d~~			~~d~~	~~d~~	~~d~~	~~d~~		X		~~d~~
		2005		X									
Common carp	*Cyprinus carpio*	2003								X			
		2004	~~d~~			~~d~~	~~d~~	~~d~~	~~d~~		X		~~d~~
		2005								X	X		
Green sunfish	*Lepomis cyanellus*	2003		X							X		
		2004	~~d~~	X		~~d~~	~~d~~	~~d~~	~~d~~		X		~~d~~
		2005											
Bass	*Micropterus sp.*	2003								X	X		
		2004	~~d~~	X		~~d~~	~~d~~	~~d~~	~~d~~		X	X	~~d~~
		2005											
Invertebrates													
Asian clam	*Corbicula fluminea*	2003									X		
		2004	~~d~~			~~d~~	~~d~~	~~d~~	~~d~~		X		~~d~~
		2005											
Crayfish	*Procambarus clarkii*	2003								X	X		
		2004	~~d~~			~~d~~	~~d~~	~~d~~	~~d~~	X	X	X	~~d~~
		2005								X	X		
Mammal													
Beaver	*Castor canadensis*	2003									X		
		2004	~~d~~			~~d~~	~~d~~	~~d~~	~~d~~		X		~~d~~
		2005											

~~d~~ = dry throughout year, although some species may have been found during night surveys

TABLE 8. NON-TARGET NATIVE AQUATIC SPECIES OBSERVATIONS

			Watershed- creek/river										
			San Mateo				San Onofre			Santa Margarita			
Common Name	Scientific Name	Year	Lower	Upper	Crist-ianitos	Talega	Lower	Upper	Jardine	Lower	Upper	Deluz	Roblar
Amphibians		*Block*	*39-41*	*42-50*	*51-53*	*54-60*	*27-32*	*33-36*	*37-38*	*1-10*	*11-20*	*21-25*	*26*
Western toad	*Bufo boreas*	2003	X	X	X	X	X		X	X	X	X	
		2004	~~d~~	X		~~d~~	X	X	~~d~~		X	X	~~d~~
		2005	X	X	X	X	X	X	X	X	X	X	
California tree frog	*Hyla cadavarina*	2003					X					X	X
		2004	~~d~~	X		~~d~~	~~d~~	~~d~~	~~d~~		X	X	~~d~~
		2005		X	X	X	X	X			X	X	X
Pacific chorus frog	*Hyla regilla*	2003	X	X	X	X	X	X	X	X	X	X	X
		2004	X	X	X	~~d~~	X	X	~~d~~	X	X	X	~~d~~
		2005	X	X	X	X	X	X	X	X	X	X	X
California newt	*Taricha torosa*	2003											X
		2004	~~d~~			~~d~~	~~d~~	~~d~~	~~d~~			X	~~d~~
		2005											X
Fish													
Arroyo chub	*Gila orcutti*	2003								X	X		
		2004	~~d~~			~~d~~	~~d~~	~~d~~	~~d~~	X		X	~~d~~
		2005								X		X	
Reptile													
Two-striped garter	*Thamnophis hammondii*	2003		X	X	X	X		X	X		X	X
		2004	~~d~~	X	X	~~d~~	X	~~d~~	~~d~~		X		~~d~~
		2005		X	X	X		X		X	X	X	X

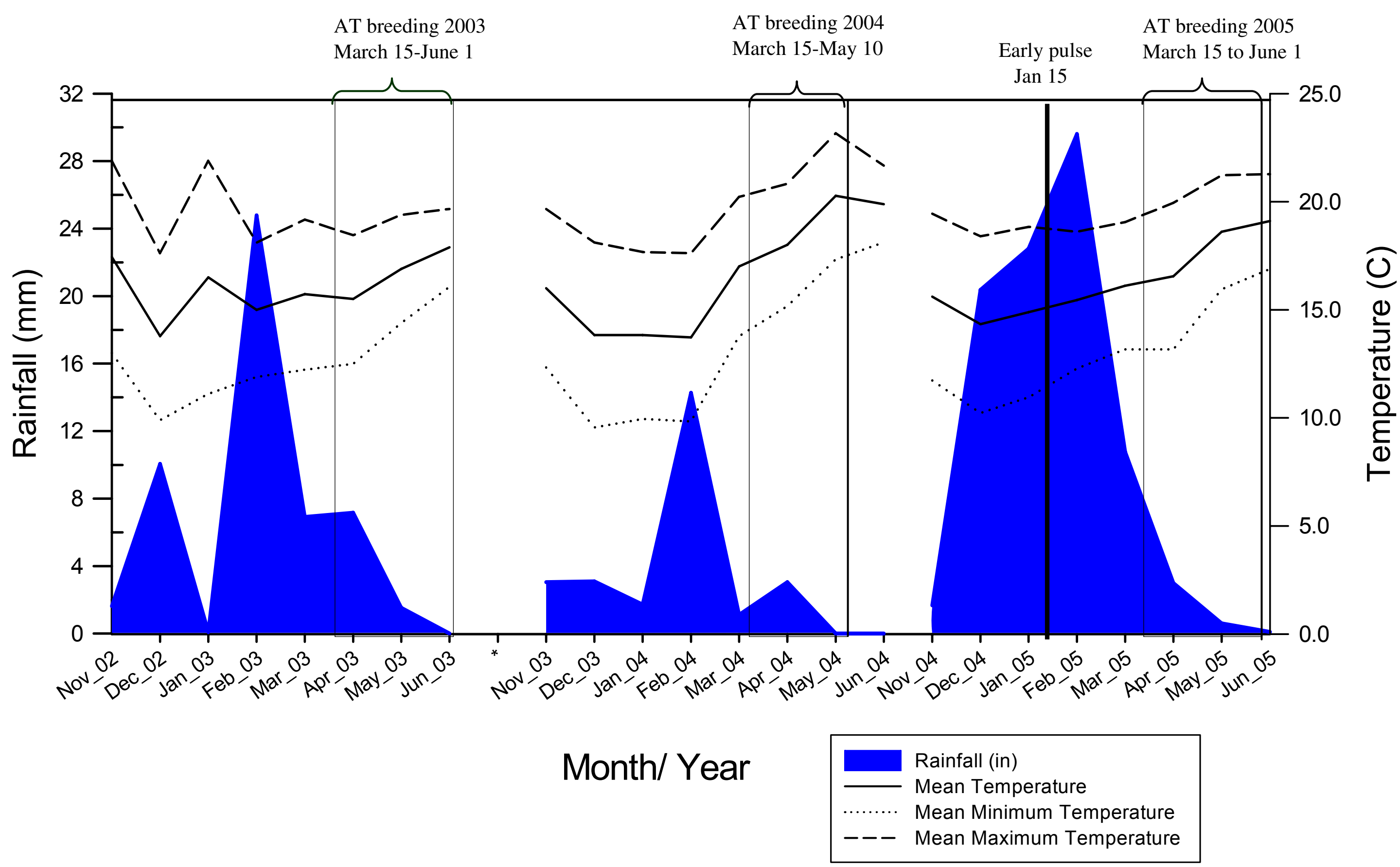
~~d~~ = dry throughout year, although some species may have been found during night surveys

Arroyo Toad: Initiation of breeding

Mean air temperatures warmed to approximately 15°C (60°F) in January, March, and February of 2003, 2004, and 2005, respectively (National Climate Data Center 2006). Rainfall peaked in February of each year and arroyo toads began breeding consistently in mid-March when the rainfall largely subsided. Breeding dates were based upon the following observations. In 2003, we first observed egg masses and two to three week old tadpoles on April 1st and 10th along the San Mateo watershed (upper and lower San Mateo Creek, Talega Creek). In 2004, when the San Mateo and San Onofre watersheds were largely dry, two to three week old tadpoles were documented on April 1 at a single pool in Cristianitos Creek. In 2005, we recorded a pulse of early breeding on January 31 in Talega and Cristianitos Creeks after several abnormal days of warm weather and rainfall. However, breeding on a much larger scale was documented to start in early to mid-March of that year as egg masses and hatchlings were observed in Cristianitos Creek on March 16, followed by 2 to 3 week old tadpoles on

March 30. Two-3 week old tadpoles were also observed in lower San Mateo and San Onofre Creeks on March 30 and April 4 of that year. Arroyo toad breeding was not temporally homogenous across the base. In all 3 years, we observed that the timing of breeding largely followed a hydroperiod gradient, with toads laying eggs at the earliest dates in the lower order streams with the shortest hydroperiod (typically between mid-March to mid-April in Talega, lower San Onofre, lower San Mateo, and Cristianitos Creeks) with an approximate one month delay before laying eggs along the largely perennial Santa Margarita River (mid-April through May/June). Periods of breeding on MCBCP were taken from egg mass records and from back-calculating ages of young larvae. These periods are presented overlaying monthly rainfall and mean, mean minimum, and mean maximum temperatures from 2003 to 2005 (Figure 5).

FIGURE 5: ARROYO TOAD BREEDING PERIODS AND CLIMATIC DATA



Arroyo Toad: Proportion Area Occupied (PAO)

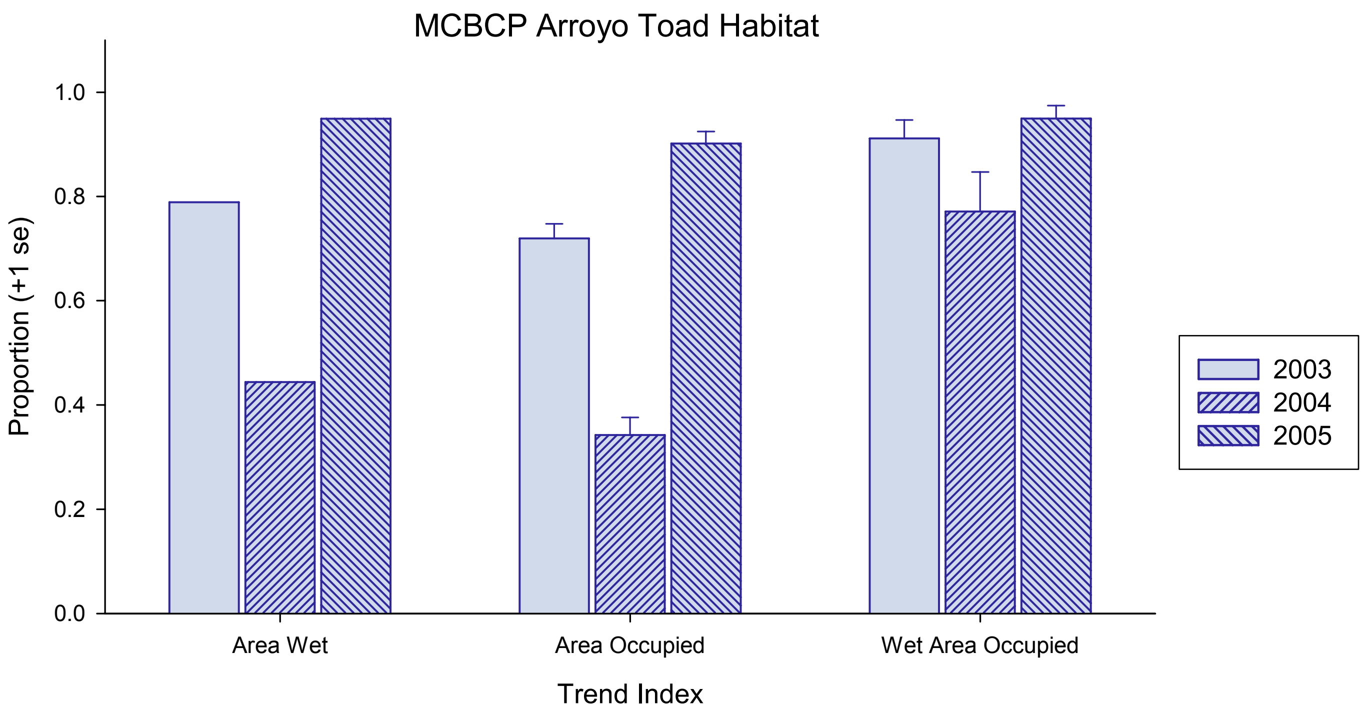
The proportion of arroyo toad habitat on MCBCP that contained surface water during breeding season was highly variable among years (44- 95%). Similarly, the percentage of habitat occupied by breeding toads was highly variable (34-90%). Normalizing the data for available surface water resulted in a more stable metric for arroyo toad occupancy on base (77-95%). Using this metric, we found a 15.4% (95% CL; 8.5 to 22.3) overall decline in occupied habitat from 2003 to 2004, followed by a 23.2 % (95% CL; -1.5 to 47.8) increase in 2005. Over the first three years of monitoring, there was an insignificant 4.2% (95% CL; -5.3 to 13.7) increase in occupancy (Table 9, Figure 6).

From 2003 to 2005, the mean percentage of habitat occupied by breeding toads was more variable along the ephemeral watersheds, San Mateo (0-97.9%) and San Onofre (0-91.2%), than the predictably seasonal Santa Margarita watershed (81.4- 99.5%). In the ephemeral watersheds, no breeding was documented in 2004 because of dry conditions. In comparing the wet years, 2003 and 2005, there were no significant changes in occupancy in these watersheds. In all years, the Santa Margarita River contained water during the spring months (predictably seasonal). In 2004, there was an insignificant decrease in occupied breeding habitat of 4.0% from 2003, followed by a significant 22.1% increase in 2005 (Table 9, Figure 7).

TABLE 9. TRENDS IN ARROYO TOAD OCCUPANCY WITHIN AND AMONG WATERSHEDS

		2003	2004	2005
All MCBCP Arroyo Toad Habitat				
	% Area wet	78.9	44.4	94.9
	% Area Occupied (se)	72.0 (2.8)	34.2 (3.4)	90.1 (2.3)
	% Wet Area Occupied (se)	91.1 (3.5)	77.1 (7.6)	95.0 (2.5)
	Detection Probability (average, se)		88.5 (0.02)	
Among Watersheds				
Santa Margarita				
	% Area wet	100.0	96.2	100.0
	% Area Occupied	84.8 (5.9)	78.5 (7.3)	99.5 (2.1)
	% Wet Area Occupied	84.8 (5.9)	81.6 (7.6)	99.5 (2.1)
San Mateo				
	% Area wet	68.2	4.9	86.4
	% Area Occupied	66.7 (4.4)	0.0	74.5 (5.5)
	% Wet Area Occupied	97.9 (6.5)	0.0	86.2 (6.4)
San Onofre				
	% Area wet	44.4	0.0	100.0
	% Area Occupied	40.4 (3.9)	0.0	91.9 (6.2)
	% Wet Area Occupied	90.9 (8.7)	0.0	91.9 (6.2)

FIGURE 6. TRENDS IN ARROYO TOAD OCCUPANCY ON MCBCP



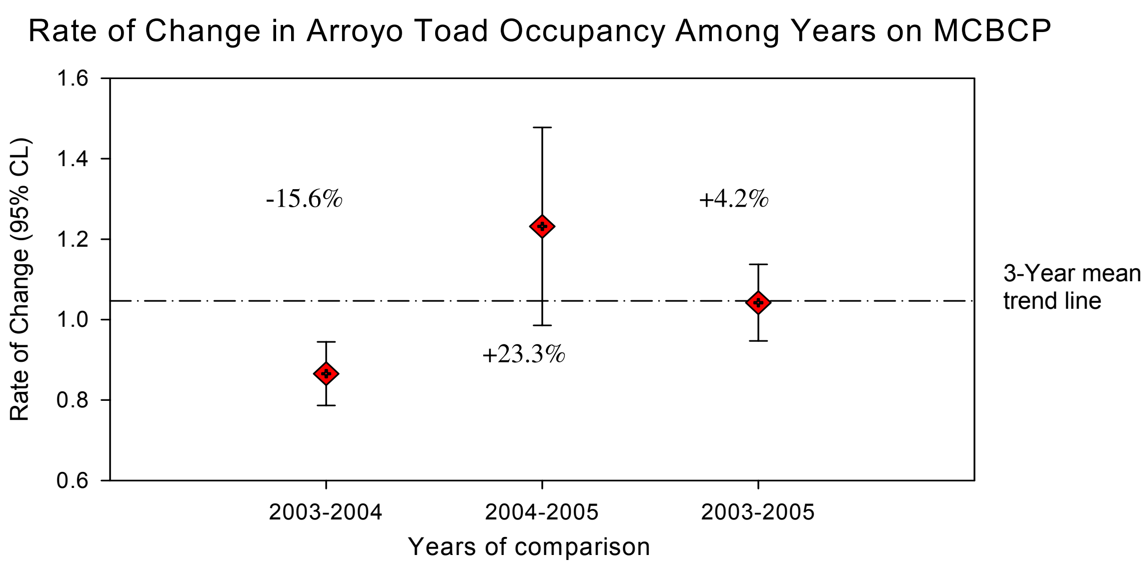
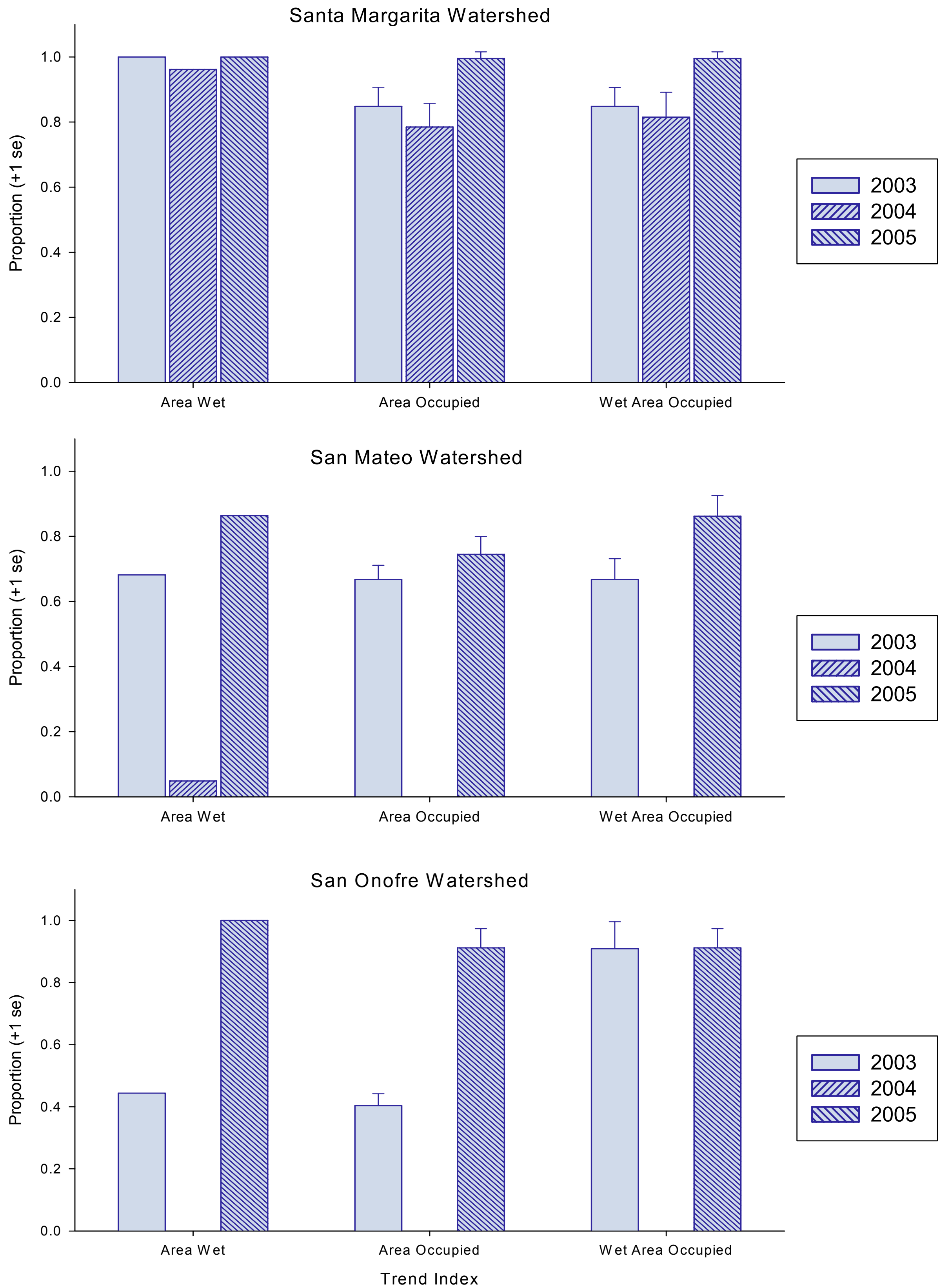


FIGURE 7. TRENDS IN ARROYO TOAD OCCUPANCY AMONG WATERSHEDS



Due to the increased number of environmental covariates recorded since 2004, we generated PAO models over two different time spans; 1) 2003 to 2005 three year models and 2) 2004 to 2005 two year models. For each set of predictive models, covariates that significantly explain variability in detection probability (ρ), occupancy (ψ), and colonization (γ) of arroyo toad larvae are presented. All models included extinction (ε) calculated as a function of colonization (ε =1-γ), because convergence could not be reached when the two parameters were estimated separately.

2003-2005 Three Year Models

Two similar models best explained the variability in arroyo toad observations and accounted for 94% of total model weights (Table 10). In both, the non-native species index was the strongest predictor of detecting arroyo toad larvae (ρ). The non-native species index ranges from 0-4 and represents a count of the following species (or groups of species) observed within a 250 m site: mosquitofish (GAAF), bullfrog (RACA), large predatory fish (includes bass, catfish, bluegill, green sunfish, and common carp-PFISH), and crayfish (PRCL). On any given survey, the probability of detecting toad eggs and larvae decreased an average of 2.3 times for each additional aquatic non-native species/group, so at a site where we found all four non-native species/groups, we were 30.0 times less likely to find arroyo toad larvae. The average probability of detecting arroyo toad larvae if they were present was 0.88 (se= 0.02).

TABLE 10. ARROYO TOAD 3-YEAR OCCUPANCY MODEL COMPARISON 2003-2005

PARAMETERS: OCCUPANCY= PSI (ψ), COLONIZATION= GAMMA (γ), EXTINCTION= 1-GAMMA, DETECTION PROBABILITY= P (ρ)

Model	AIC	AICc	delta AIC	AIC wgt	Model Likelihood	No.Par.	(-2*LogLike)	
psi(PRCL03),gam(SEASON),eps=1-gam,p(NONNATINDEX)	376.88	378.56	0.10	0.50	1.00	6	364.88	*best models*
psi(NNI03),gam(SEASON),eps=1-gam,p(NONNATINDEX)	377.11	378.79	0.33	0.44	0.89	6	365.11	*in green*
psi(.),gam(SEASON),eps=1-gam,p(NONNATINDEX)	382.59	383.77	5.31	0.03	0.06	5	372.59	
psi(PRCL03),gam(SEASON),eps=1-gam,p(PRCL)	382.90	384.58	6.12	0.02	0.05	6	370.90	
psi(.),gam(.),eps=1-gam,p(NONNATINDEX)	386.71	387.48	9.02	0.00	0.00	4	378.71	
psi(.),gam(SEASON),eps=1-gam,p(PRCL)	388.33	389.51	11.05	0.00	0.01	5	378.34	
psi(PRCL03),gam(SEASON),eps=1-gam,p(SEASON)	391.33	393.62	15.16	0.00	0.00	7	377.33	
psi(NNI03),gam(SEASON),eps=1-gam,p(SEASON)	391.48	393.77	15.31	0.00	0.00	7	377.48	
psi(.),gam(.),eps=1-gam,p(PRCL)	396.77	397.54	19.08	0.00	0.00	4	388.77	
psi(.),gam(SEASON),eps=1-gam,p(SEASON)	400.58	402.26	23.80	0.00	0.00	6	388.58	*ρ & γ vary by year*
psi(.),gam(.),eps=1-gam,p(BUBO)	402.35	403.12	24.66	0.00	0.00	4	394.35	
psi(.),gam(.),eps=1-gam,p(SEASON)	403.98	405.16	26.70	0.00	0.00	5	393.98	*ρ varies by year*
psi(.),gam(.),eps=1-gam,p(PFISH)	407.98	408.75	30.29	0.00	0.00	4	399.98	
psi(.),gam(.),eps=1-gam,p(GAAF)	409.17	409.94	31.48	0.00	0.00	4	401.17	
psi(.),gam(.),eps=1-gam,p(RACA)	414.77	415.54	37.08	0.00	0.00	4	406.77	
psi(.),gam(.),eps=1-gam,p()	419.41	419.86	41.40	0.00	0.00	3	413.41	*null model*

Note: Other covariates tested for psi & gamma: Disturbance Index, Aquatic Vegetation Cover Index, Entrenchment Ratio, Upland Veg Cover, Hydroperiod same year, Hydroperiod previous year, Sand Cover, Non-native Species Index (same year), PRCL presence. Models are not shown if AIC values were less than the control or if models showed evidence of very poor fit (no convergence, no covariance matrix, standard errors > parameter estimates).

Initial occupancy (ψ) for arroyo toads in 2003 was best explained by the presence of crayfish (model weight 0.47) and/or the non-native species index (model weight 0.42). The odds that arroyo toads occupied a site were 11.6 times lower when crayfish were present and 2.9 times lower for each additional aquatic non-native species/group, so that at a site with all four non-native species/groups, we had 70 times less odds of finding arroyo toad larvae.

The model including year (SEASON) was superior to the model that assumed colonization (γ) was constant over time (ΔAIC_c~4), indicating the rate of colonization/extinction was not constant over the three year period. From 2003 to 2004, the odds were 3.3:1 of an unoccupied site becoming occupied (probability 0.77). From 2004 to 2005, the odds increased to 19:1 (probability 0.95).

2004-2005 Two Year Models

The larger number of landscape and water variables collected in 2004 and 2005 allowed us to test an expanded set of hypothetical models, however, the overall data set was smaller (2 vs. 3 years) and only simple models were able to fit the data in PRESENCE (Table 11). Of these, a single model in which low flow index is predictive of arroyo toad detection probability (ρ) emerged as most predictive of the data (model weight 1.0). The low flow index represents a measure of the amount of low flow shallow water (or appropriate breeding habitat) present within a 250 m site. The index ranges from 0-5 as a percentage of site length from 0 %, 1-10%, 11-25%, 26-50%, 51-75%, and 76-100%, respectively. For these analyses, the 0 and 1 indices were combined into the 1 index (0-10%) due to low numbers of 0 values. From 2003 to 2004, the odds of detecting a toad averaged 2.14 (se=0.12) fold higher for each increase in the low flow index, so at a site that contained 75 to 100% low flow shallow water, we had 21.0 times higher odds of finding to find arroyo toad larvae than a site that contained less than 10%. Although this model outperformed all other models, models that included non-native species index as a predictor of ρ were second best (ΔAIC_c~14) and still far superior than the null model (ΔAIC_c~18). In these models, the odds that arroyo toads were detected averaged 2.3 (se=0.18) fold less for each additional aquatic non-native species/class, so in a site containing all four non-native species/classes, we we had 29.0 times lower odds of finding arroyo toad larvae.

TABLE 11. ARROYO TOAD 2-YEAR OCCUPANCY MODEL COMPARISON 2004-2005

PARAMETERS: OCCUPANCY= PSI (ψ), COLONIZATION= GAMMA (γ), EXTINCTION= 1-GAMMA, DETECTION PROBABILITY= P (ρ)

Model	AIC	AICc	delta AICc	AICc wgt	Model Likelihood	No.Par.	(-2*LogLike)	
psi(.),gam(.),eps=1-gam,p(LOWFLOW_INDEX)	231.51	232.28	0.00	1.00	1.00	4	223.51	*best model*
psi(.),gam(SAND),eps=1-gam,p(NONNATIVE_INDEX)	245.80	246.98	14.70	0.00	0.00	5	235.80	
psi(.),gam(.),eps=1-gam,p(NONNATIVE_INDEX)	246.64	247.41	15.13	0.00	0.00	4	238.64	
psi(.),gam(.),eps=1-gam,p(BUBO)	252.11	253.15	20.87	0.00	0.00	4	244.11	
psi(SAND),gam(.),eps=1-gam,p(SEASON)	251.97	252.88	20.60	0.00	0.00	5	241.97	
psi(.),gam(.),eps=1-gam,p(PRCL)	254.99	255.76	23.48	0.00	0.00	4	246.99	
psi(.),gam(.),eps=1-gam,p(SEASON)	255.03	255.79	23.51	0.00	0.00	4	247.03	*ρ varies by year*
psi(.),gam(.),eps=1-gam,p(PREDATORYFISH)	255.49	256.25	23.97	0.00	0.00	4	247.49	
psi(.),gam(.),eps=1-gam,p(CHANNELVEG_COVER)	256.14	256.91	24.63	0.00	0.00	4	248.14	
psi(SAND),gam(.),eps=1-gam,p(.)	260.79	261.56	29.28	0.00	0.00	4	252.79	
psi(.),gam(.),eps=1-gam,p(RACA)	261.28	262.05	29.77	0.00	0.00	4	253.28	
psi(.),gam(.),eps=1-gam,p()	263.92	264.37	32.09	0.00	0.00	3	257.92	*null model*
psi,gamma(),eps(),p()	265.84	266.61	34.33	0.00	0.00	4	257.84	

Note: Other covariates tested for psi & gamma: Disturbance Index, Aquatic Vegetation Cover Index, Entrenchment Ratio, Upland Veg Cover, Hydroperiod same year, Hydroperiod previous year, Sand Cover, Non-native Species Index (same year), PRCL presence. Models are not shown if AIC values were less than the control or if models showed evidence of very poor fit (no convergence, no covariance matrix, standard errors > parameter estimates).

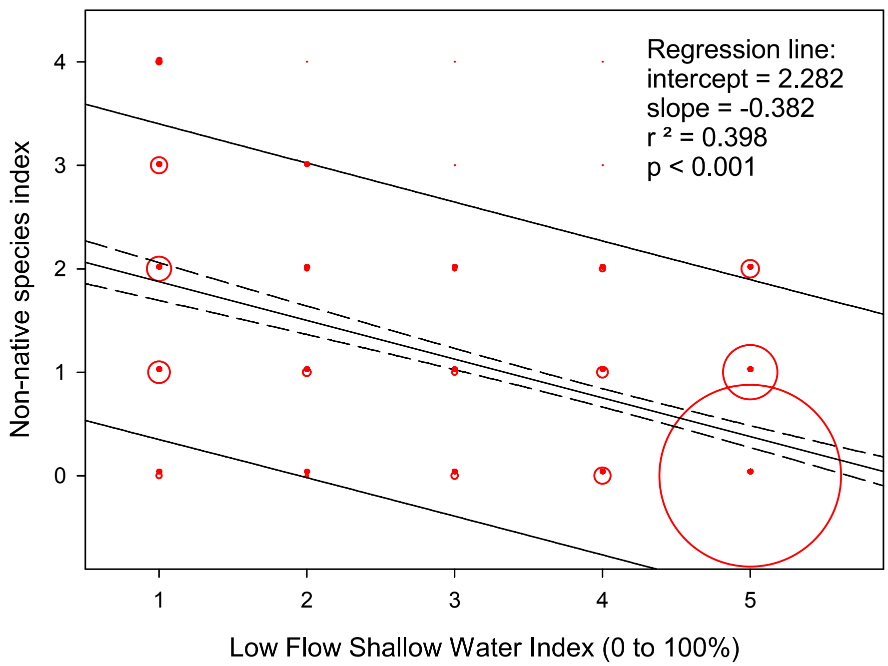
We explored the relationship between non-native species index, crayfish presence and low flow index. We found that crayfish and other non-native species were more likely to be found in sites with deeper and faster flowing water (lesser proportions of low flow water). Crayfish presence is a component of the low flow index, so these measures are not independent. However, crayfish presence was not significantly correlated with non-native species index (Spearman r= 0.3, p=0.624.). PAO models and regression analyses showed that the amount of low flow water is a significant predictor of both crayfish presence and number of non-native species (Table 12, Figure 8). For each ordinal increase in the low flow index, the odds of detecting crayfish were reduced by1.9 (se=0.19). Therefore, the odds of detecting crayfish were 13.0 times greater when there was less than 10% low flow shallow water in a site than when there was 100%. Similarly, for each ordinal increase in the low flow index, there was an average corresponding decrease of 0.38 (se=0.03) in the non-native index. We observed an average of 2.3 non-native species/groups when the site contained ≤10% low flow shallow water in comparison to 0.4 observed when the site contained 100% low flow shallow water.

TABLE 12. CRAYFISH (PRCL) OCCUPANCY MODELS 2004-2005

Model	AIC	AICc	delta AICc	AICc wgt	Model Likelihood	No.Par.	(-2*LogLike)
psi(.),gam(.),eps=1-gam,p(LOWFLOW)	159.05	159.82	0.00	1.00	1.00	4	151.05
psi(.),gam(.),eps=1-gam,p()	170.35	170.81	10.99	0.00	0.00	3	164.35
psi,gamma(),eps(),p()	171.33	172.10	12.28	0.00	0.00	4	163.33
1 group, Constant P	222.54	222.76	62.94	0.00	0.00	2	218.54

**model with p (season) did not converge*

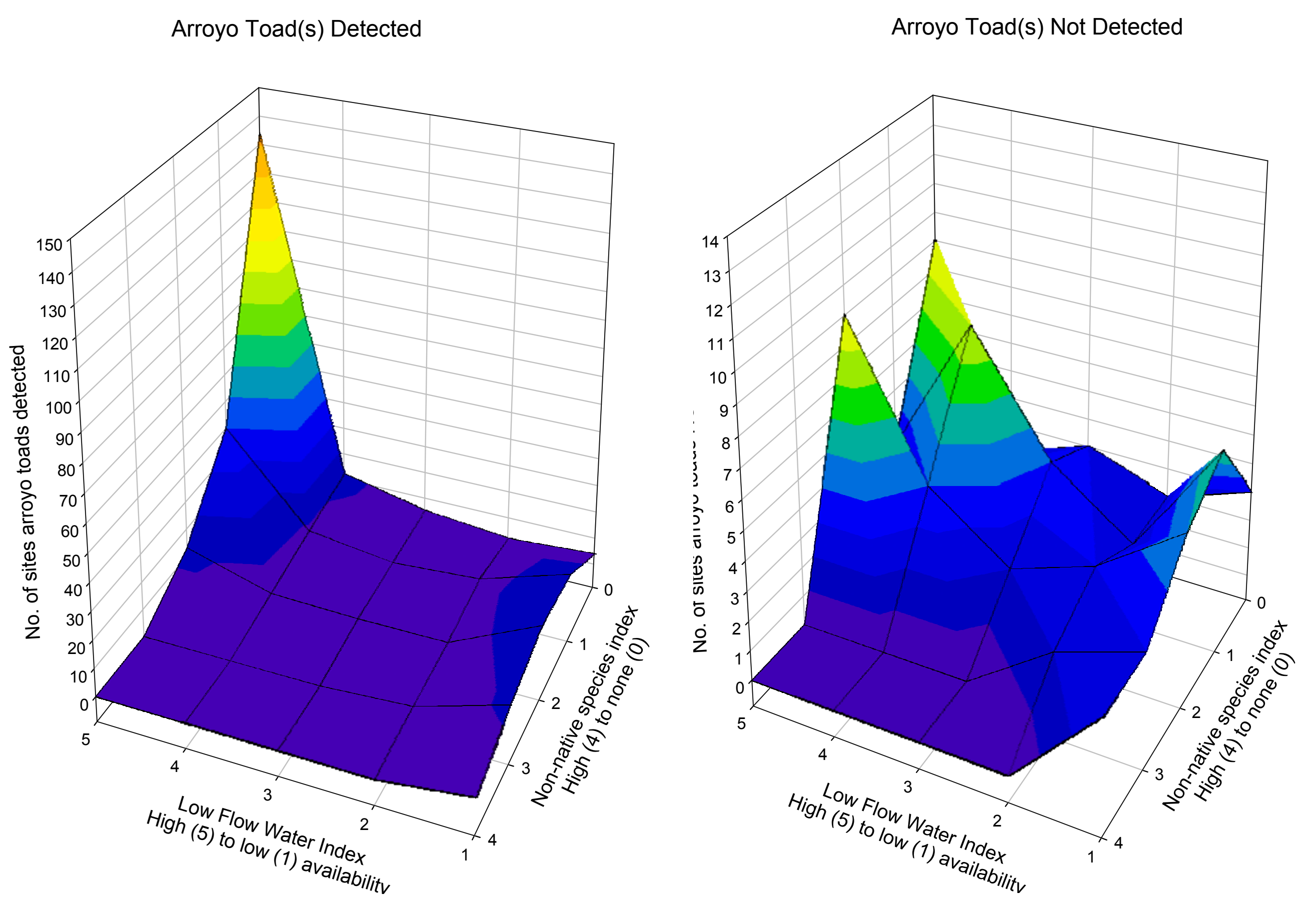
FIGURE 8: RELATIONSHIP BETWEEN LOW FLOW SHALLOW WATER AND NON-NATIVE SPECIES INDICES



Bubble Plot: Size of bubbles correspond to number of surveys with specific values of indices

The relationship among arroyo toad presence and indices of non-native species and low flow water are displayed graphically in Figure 9. The large majority of sites where arroyo toad eggs and/or larvae were detected contained at least 76% (190 meters) of available low flow shallow water and ≤1 non-native species/groups. In contrast, when arroyo toads were not detected, water flow values and numbers of non-native species were more evenly distributed. These figures include all surveys within and among years.

FIGURE 9: ARROYO TOAD PRESENCE IN RELATION TO LOW FLOW SHALLOW WATER AND NON-NATIVE SPECIES INDICES



Arroyo Toad: Trends in Adult Counts from 1996 to 2005

Adult count data may be interpreted as a combined function of both arroyo toad abundance and activity patterns. From 2003 to 2005, we surveyed each of the eight 1-km transects established by Holland *et al.* (2001) three to four times per year. Combining these data, we found that evening counts of adult toads continued to be highly variable both within and among transects. From 1996 to 2005, there was an average of 7.8 adult arroyo toads (>4 cm in length) observed per survey per site with annual variability peaking at +/- 44% of the mean. Over the entire ten year period, there was an insignificant decrease of 5.4% ($r^2 = 0.005$, $p=0.868$), indicating that despite extreme short term fluctuations, there were no detectable long term trends in arroyo toad activity over the past decade (Figure 10).

Using all of the individual count data, we tested for main and interactive effects from site, year, rainfall, and hydroperiod using forward stepwise multiple regression. Regression models containing site, hydroperiod, and rainfall explained 25.1% of variability in toad counts ($F_{7,208}=11.32$, $p<0.0001$). Year was not a significant predictor, site accounted for 22.2% of the total variability (Total $F_{5,208} = 55.05$, range of p-values <0.0001-0.0534), and 3.1% of the total variability was explained by a very significant hydroperiod*rainfall interaction ($t_{1,208}= 4.17$, $p<0.0001$). This interaction revealed that the effect of rainfall on arroyo toad counts is dependent upon hydroperiod. In sites containing predictable seasonal water flow (upper and lower Santa Margarita), rainfall was not a predictor of toad counts. In the ephemeral creeks, rainfall was a positive predictor of arroyo toad counts, as successively higher numbers of toads were observed in years with more rainfall. The regression lines and plots of the interaction between hydroperiodicity and rainfall are shown in Figure 11.

We also continue to follow the yearly trends in the number of toads observed during evening surveys within each site (Figure 12). These data are presented overlaying seasonal rainfall totals. The positive association between arroyo toad counts and rainfall in the ephemeral creeks and lack of association in the Santa Margarita River is also apparent in most of the graphs. There is also a lack of association noticeable in the DeLuz Creek transect. The hydroperiodicity of DeLuz Creek, a tributary of the Santa Margarita River, is intermittent falling between predictably seasonal and ephemeral.

FIGURE 10. OVERALL TRENDS IN MEAN NUMBER OF ADULT COUNTS FROM 1996 TO 2005

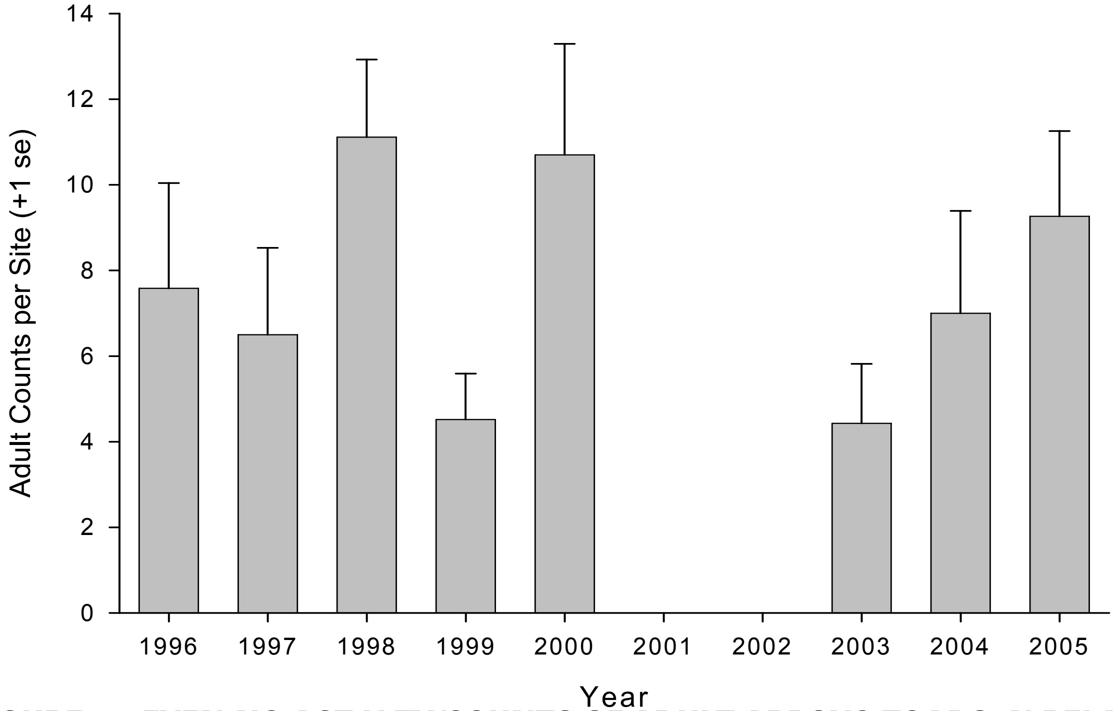


FIGURE 11. EVENING ACTIVITY/COUNTS OF ADULT ARROYO TOADS IN RELATIONSHIP TO RAINFALL AND HYDROPERIOD.

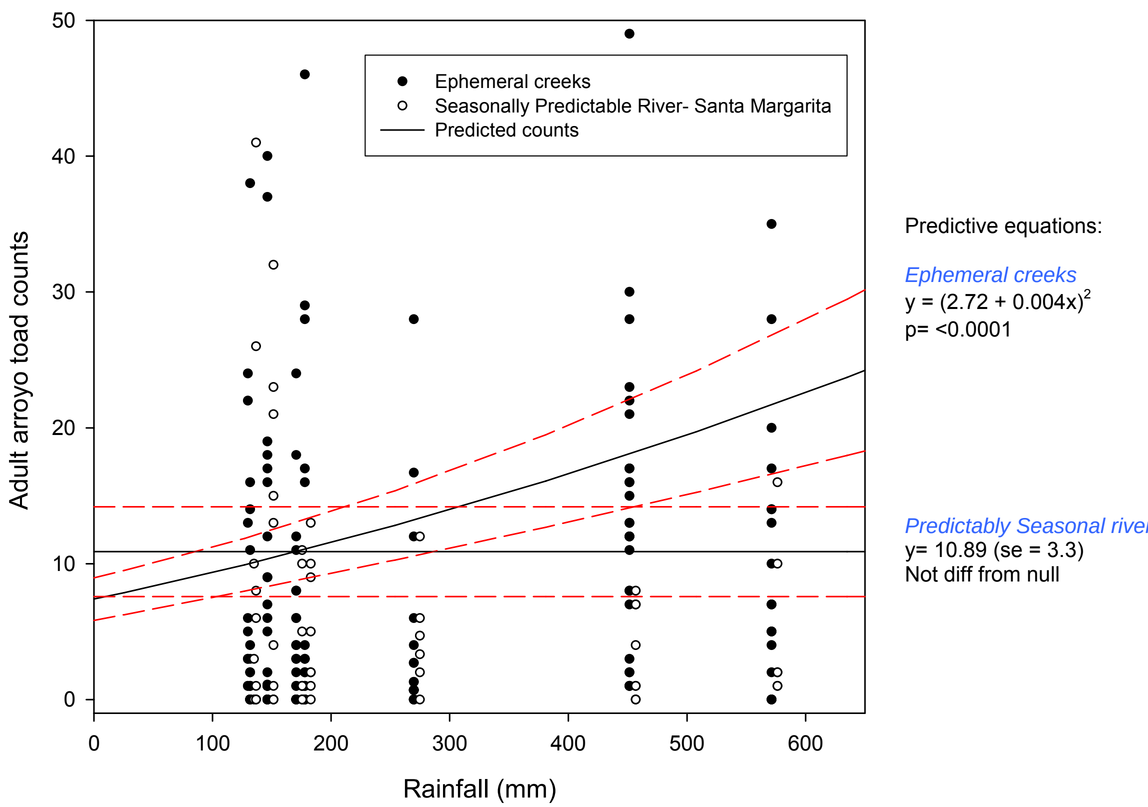
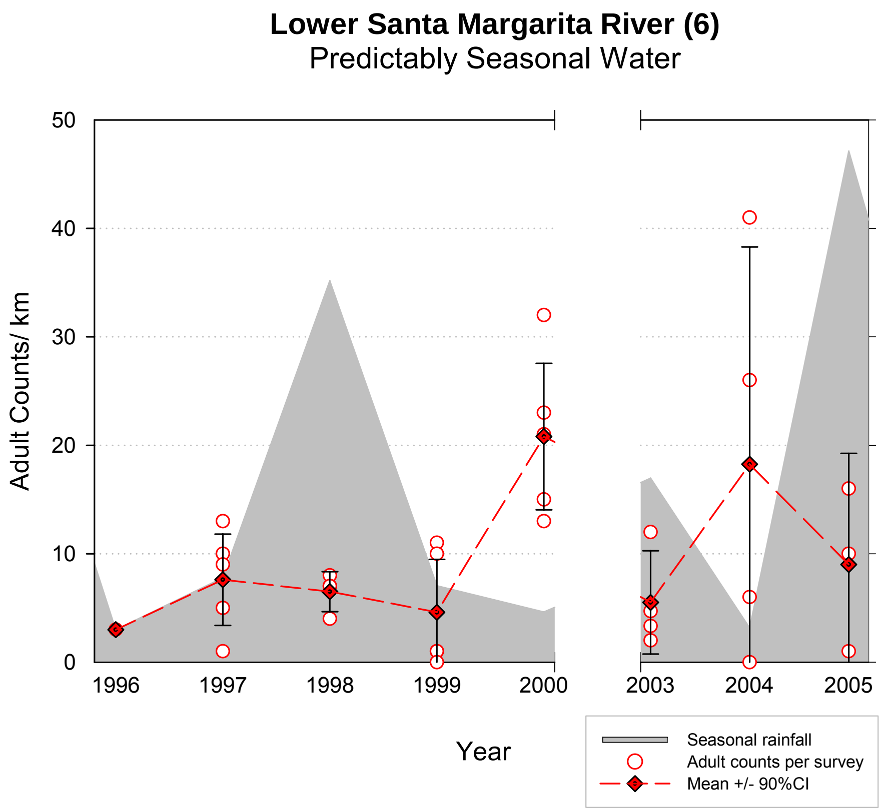
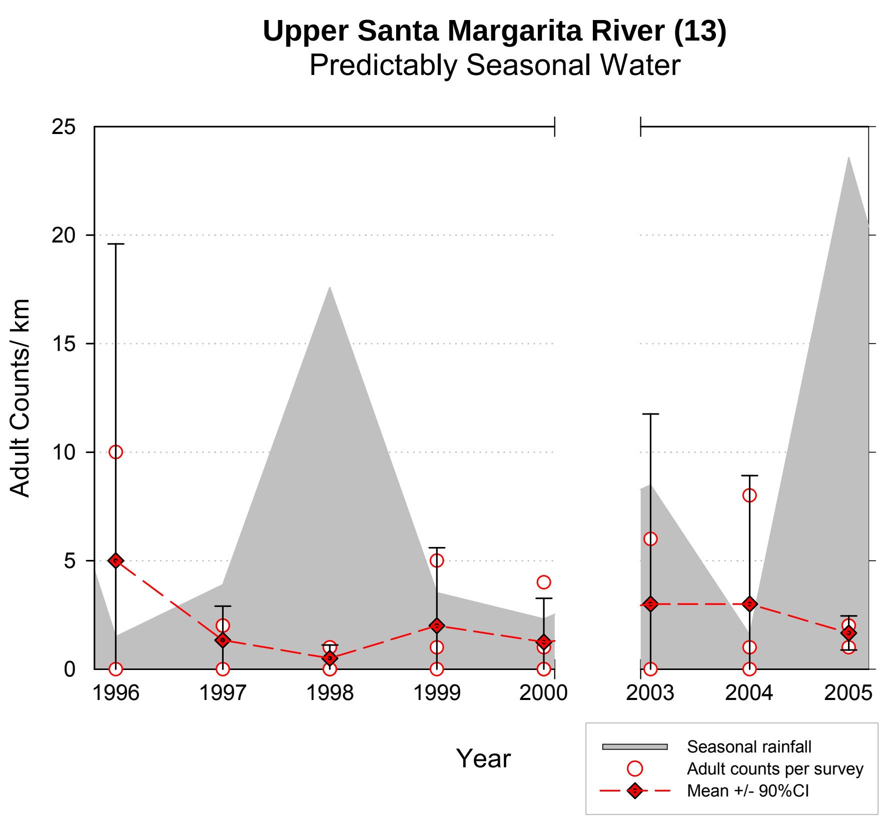
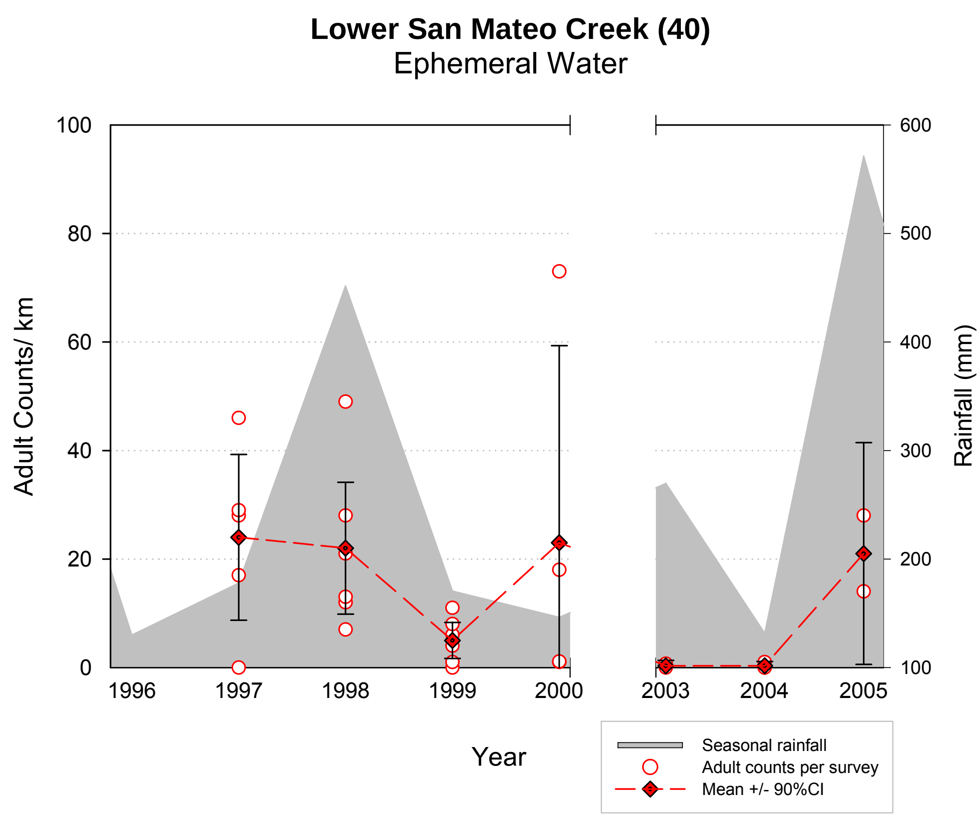


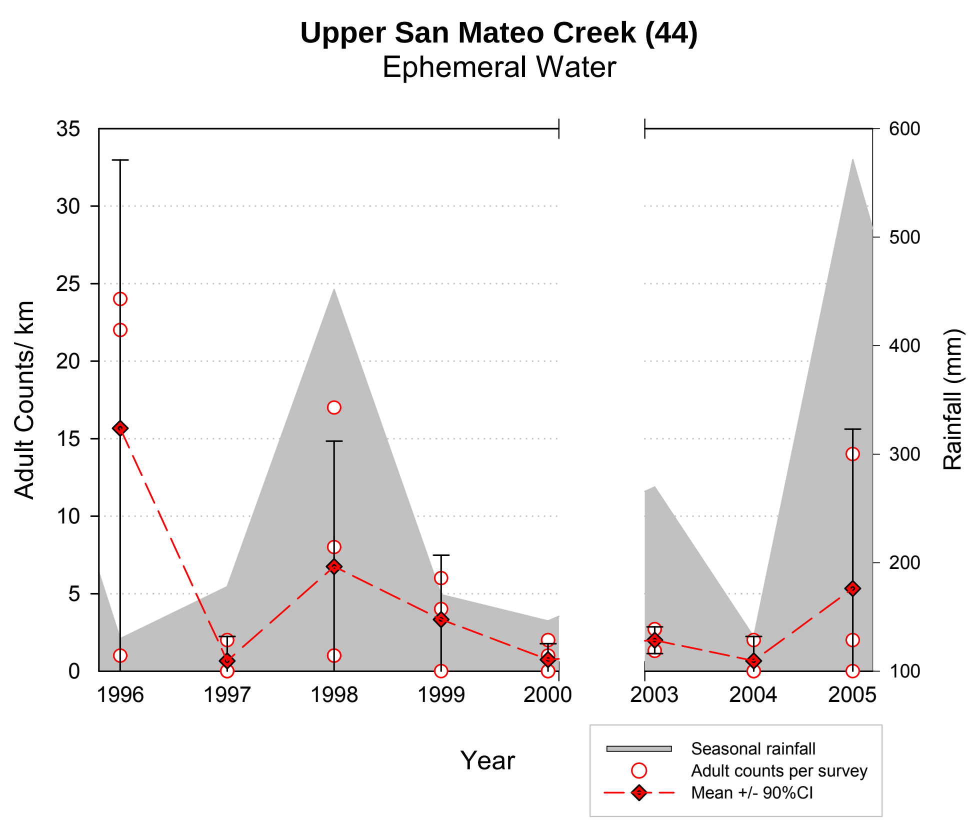
FIGURE 12. INDIVIDUAL SITE TRENDS IN MEAN NUMBER OF ADULT COUNTS IN COMPARISON TO SEASONAL RAINFALL



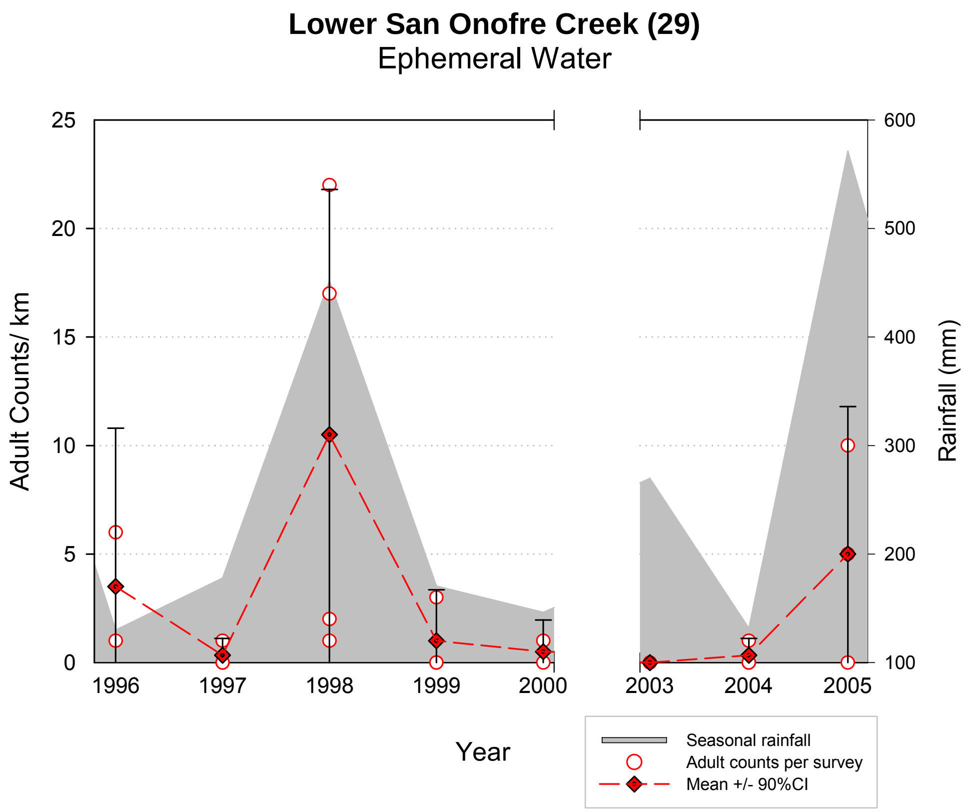




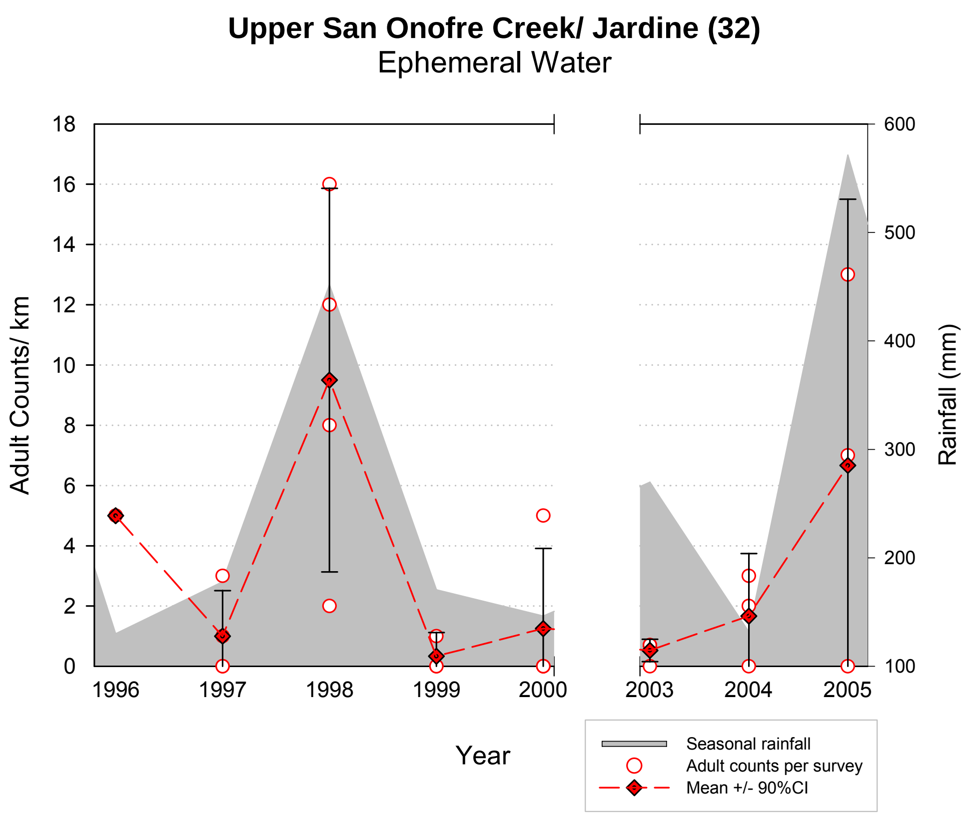
Lower San Mateo Creek (40)
Ephemeral Water
Adult Counts/ km
Rainfall (mm)
Year
0
20
40
60
80
100
100
200
300
400
500
600
1996
1997
1998
1999
2000
2003
2004
2005
Seasonal rainfall
Adult counts per survey
Mean +/- 90%CI



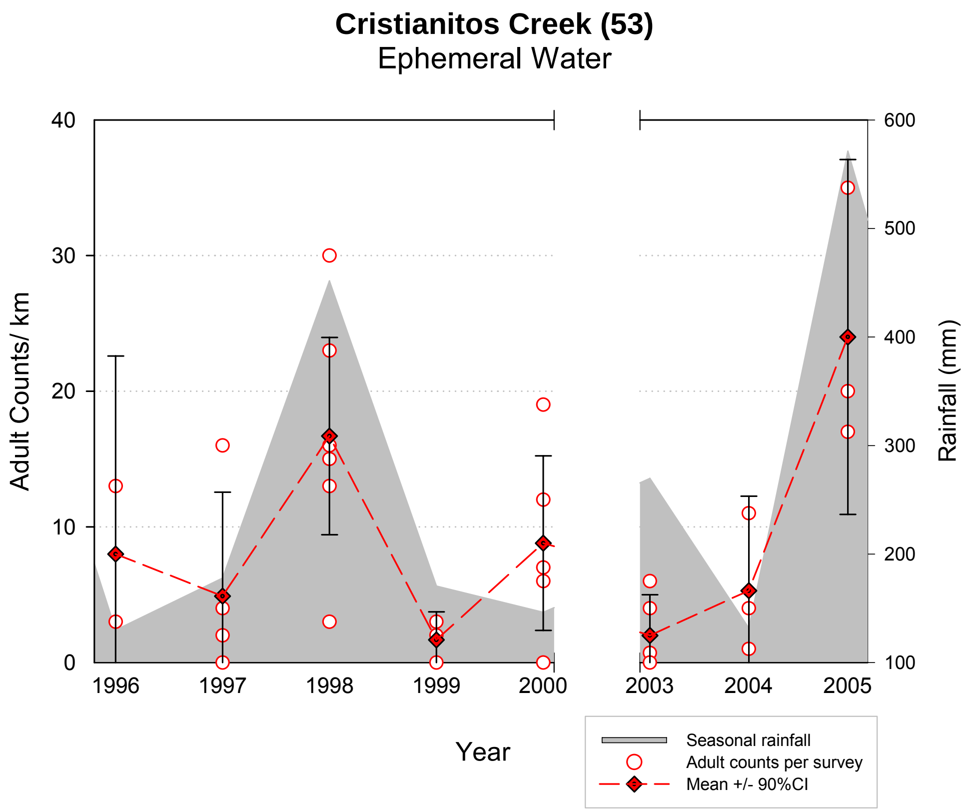
Upper San Mateo Creek (44)
Ephemeral Water
Adult Counts/ km
Rainfall (mm)
Year
0
5
10
15
20
25
30
35
100
200
300
400
500
600
1996
1997
1998
1999
2000
2003
2004
2005
Seasonal rainfall
Adult counts per survey
Mean +/- 90%CI

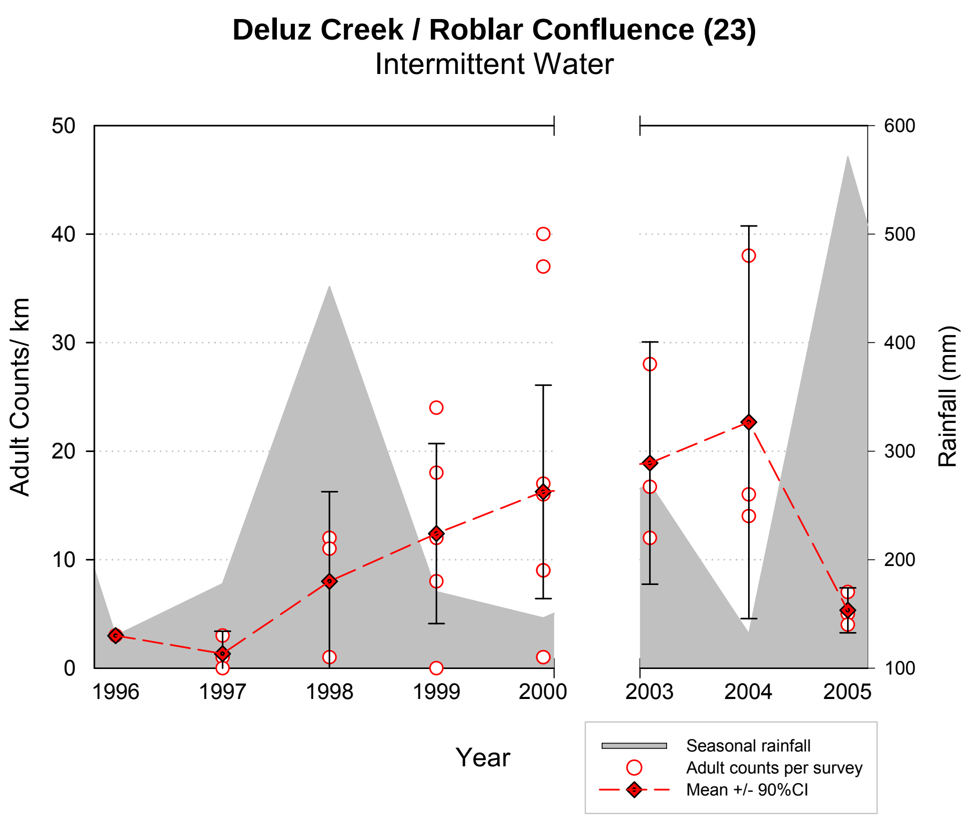


Lower San Onofre Creek (29)
Ephemeral Water
Adult Counts/ km
Rainfall (mm)
Year
0
5
10
15
20
25
100
200
300
400
500
600
1996
1997
1998
1999
2000
2003
2004
2005
Seasonal rainfall
Adult counts per survey
Mean +/- 90%CI



Upper San Onofre Creek/ Jardine (32)
Ephemeral Water
Adult Counts/ km
Rainfall (mm)
Year
0
2
4
6
8
10
12
14
16
18
100
200
300
400
500
600
1996
1997
1998
1999
2000
2003
2004
2005
Seasonal rainfall
Adult counts per survey
Mean +/- 90%CI


Cristianitos Creek (53)
Ephemeral Water
Adult Counts/ km
Rainfall (mm)
Year
1996
1997
1998
1999
2000
2003
2004
2005
Seasonal rainfall
Adult counts per survey
Mean +/- 90%CI


Deluz Creek / Roblar Confluence (23)
Intermittent Water
Adult Counts/ km
Rainfall (mm)
Year
1996
1997
1998
1999
2000
2003
2004
2005
Seasonal rainfall
Adult counts per survey
Mean +/- 90%CI

Arroyo Toad: Pit-tagged Toad Recoveries

During our night surveys in 2003, we recaptured five adult arroyo toads that had been originally PIT-tagged between 1998 and 2000 (Holland *et al.* 2001, Holland and Sisk 2001). Two individuals were captured in Cristianitos Creek, and one each in lower San Mateo Creek, Deluz Creek, and upper Santa Margarita River. According to the size (snout-to-urostyle length) at the time of marking, size upon recapture, and year the animal was PIT-tagged, we estimated the toads to be at least 4 to 5 years old at the time of recapture (Brehme *et al.* 2003). No PIT-tagged toads from the Holland study were recaptured in 2004 or 2005. These results are consistent with survivorship estimates of 5 and 6 years by Samuel Sweet (1991) and a recent skeletochronology study of arroyo toads by the USGS (R. Fisher pers. comm.).

Discussion

Trends in arroyo toad occupancy within MCBCP

The Mediterranean climate and influence from the ENSO cycle in southern California is typified by highly variable annual rainfall. In drought years, there may be no surface water available in the ephemeral creeks, while in high rainfall years there can be extensive flooding and scouring events. These conditions were all represented in our first three years of monitoring. Although the arroyo toad is reported to require permanent or predictably seasonal streams to support breeding populations (Sweet and Sullivan 2005), two of the watersheds representing 56% of arroyo toad habitat within Camp Pendleton are largely intermittent to ephemeral, only flowing in response to rain events. Thus, breeding and recruitment in these creeks only occur in normal to high rainfall years. This results in extreme annual variability in arroyo toad breeding activity and spatial distribution on base.

In tracking both the proportion of area wet each year along with the proportion of wet area occupied by breeding toads, we found that even though surface water availability was highly variable (44-95%), the overall extant of toads breeding in wet areas was relatively stable (77-95%) with no significant change when assessed over the three year period. In addition, the night survey count data from 1996 to present, also shows that arroyo toad activity has had extremely high annual variability (+/- 44% of mean), but no significant change over the last decade.

By analyzing 2-year models with a greater number of covariates, we found the probability of detecting arroyo toad larvae was positively associated with low flow shallow water and negatively associated with non-native species. These two variables were correlated with one another, so that during the arroyo toad breeding season, non-native species were associated with deep and faster flowing water. The amount of low flow shallow water was highly variable within each season. This factor was predictive of detecting tadpoles on a given survey but not predictive of annual occupancy.

In both annual occupancy and adult counts, arroyo toad dynamics appear to differ between the ephemeral watersheds and the predictably seasonal Santa Margarita River watershed. Linear regression results show that arroyo toad counts were significantly associated with the amount of rainfall for the ephemeral San Onofre and San Mateo watersheds, but not for the Santa Margarita watershed. In years of low rainfall, toads in the ephemeral systems likely spend little to no energy on breeding and spend less time foraging above ground to avoid desiccation, possibly explaining the lowered animal counts and reduced breeding distribution. In wet years, the toads breed early to increase the chances of larval metamorphosis before the surface water dries. This was evident by the earlier breeding documented in these ephemeral watersheds (mid-March and a January breeding event in 2005).

In contrast, the Santa Margarita River is predictably seasonal to perennial. Arroyo toads breed yearly regardless of rainfall patterns. Our monitoring data indicate that breeding typically occurs later in the river, from mid-April through June, depending upon surface water flow and the availability of shallow pooling water. There was a significant 27% increase in arroyo toad occupancy in this watershed in 2005. Since the river dried for several months in 2004, we suspect that non-native aquatic species were negatively impacted, as most require perennial water for survival (Gasith and Reth 1999, Adams 2000). This may have lowered predation levels of arroyo toad adults, eggs, and larvae, resulting in their increased survivorship and increased spatial distribution. This hypothesis is supported by our occupancy models as well as the reduced number of non-native species observed along the river in 2005. Although lack of convergence did not allow us to model the effect of hydroperiod on colonization and extinction parameters, the occupancy models for wet habitat did indicate that crayfish and the number of non-native species had the largest negative impact on arroyo toad occupancy and detectability. This is the most relevant for the largely perennial Santa Margarita River, which harbors the largest densities and numbers of invasive aquatic species on base that are known to depredate amphibian eggs and/or larvae (see Future Concerns). We expect that the scouring out of aquatic vegetation by the 2005 floods also created more open breeding habitat for the toads.

Therefore, arroyo toads in the lower order watersheds appear to be primarily influenced by stochastic processes (i.e. amount of rainfall), while those in the Santa Margarita Watershed are primarily influenced by deterministic processes (i.e. predation, competition, habitat alteration). If this is the case, we may expect the occupancy and abundance of toads in the San Mateo and San Onofre watersheds to be more highly variable among years (Ross *et al.* 1985, Death and Winterborn 1994, Therrault and Kolasa 2000). Early trends in our occupancy data and the night survey counts (combined Holland et al 2001 and USGS) show that annual variability is in fact much higher in these ephemeral watersheds. These populations are at increased risk of extirpation from a prolonged drought and may be more dependent upon dispersal from more stable sites for recolonization. In contrast, we should also expect less temporal variability and increased population persistence within the Santa Margarita River. Variability in both arroyo toad occupancy and adult counts has been relatively low in this watershed. However, the threat of extirpation of amphibians by non-native species predation and associated habitat loss is an immediate and well-documented threat (See Future Concerns and Management Recommendations; review by Kats and Ferrer 2003). Diseases, especially chytridomycosis, could also influence arroyo toad population dynamics in the future.

It is important for us to understand the change in the spatial extant and abundance of toads over both the short term and the long term on MCB Camp Pendleton. As we have discussed, in such widely variable populations, threat of extirpation can lie in both extraordinary short term stochastic events (i.e. disease, weather and water extremes, excessive predation) or longer term responses to negative environmental conditions (habitat loss, stream channelization, water pollution, predation/competition with invasive species). Often, no one factor alone is responsible, but occurs because of a combination of stressors (Carey *et al.* 2003, Bridges and Little 2005). By understanding the factors that have the greatest influence on the arroyo toad, we can take early management action to lessen the chances of extirpation.

Evaluation of PAO monitoring program

In employing a spatial monitoring approach, we hoped that proportion area occupied (PAO) would be a more stable metric than species abundance or activity, so that we could better track long-term population trends in addition to annual variability (Atkinson *et al.* 2002). The first three years of data support this assumption, as the relative range in proportion of wet area occupied (0.77-0.95) was 1.6-times lower than the range of average adult counts over the same period (4.4-9.3). Precision of annual PAO estimates were also substantially better, averaging 5.4% of the overall mean in comparison to 29.0% of the overall mean for adult counts. Even when the standard errors are normalized to account for the difference in number of surveys per year, the adult count error term is still over twice as large as that for PAO (12.1%). As expected, estimates of population change using data from multiple years were smaller than between any two years and the overall change in PAO estimates from 2003 to 2005 was insignificant (+4.20%, se= 0.48).

From a conservation and management perspective, in adopting a PAO metric as a representative index for tracking the health of arroyo toad populations, there is also an underlying assumption that proportion area occupied is somehow correlated to overall abundance. Thus, we may expect that when toad populations are more abundant over the landscape, they are present in a larger proportion of locations within the landscape. Nielson *et al.* (2005) proposed that this relationship is strong at higher animal densities, in landscapes with patchy resources, and for species with low territorial behavior (i.e. territory is resource driven). We do not yet have the dataset required to evaluate these hypotheses for the arroyo toad using night survey counts. A more appropriate treatment would involve the collection of some type of arroyo toad abundance data during the PAO surveys. This could serve as a second method to track trends in arroyo toad numbers and be used to model effects of larval abundance on detection probabilities (Royle 2004). In addition, the relationship between abundance and probability of detection can be exploited to estimate arroyo toad abundance (Royle and Nichols 2003). We propose to add and evaluate several indices of larval toad abundance to the day survey protocol. These are detailed in the Recommendations section.

The study design allowed us to evaluate the relationship of environmental and landscape variables to arroyo toad breeding and detection. This is a particularly strong benefit to the monitoring design, as significant relationships may be used to make informed habitat and predator-control management decisions. Our significant results with number of non-native species, crayfish presence, and amount of low flow shallow water on arroyo toad parameters are good examples of this. However, even with the highly significant results, PAO models of the MCBCP data were somewhat limited. For the most part, particularly with the two-year dataset of 2004-2005, we were unable to evaluate models that are more complex or those with more than two or three covariates. Arroyo toad occupancy and detectability was so high among years, that there was relatively little variability to model. We believe that this is why we were not able to model the effect of hydroperiod on colonization and extinction probabilities for the 3-year dataset, as lack of convergence is a sign of overfitting. Darryl MacKenzie (pers. comm.) suggests the most powerful modeling abilities occur with occupancy values between 0.2 and 0.8 and detectability of 0.5 or more. Therefore, we expect the current program will be better at detecting causes of species decline versus growth. Addition of lesser quality habitat and shorter survey site lengths (i.e. 100 m vs. 250 m) could be potential approaches to reducing occupancy levels for the model.

Future Concerns

We expect the effects of urbanization, occurring largely outside the base, may be a primary threat to the arroyo toad in MCB Camp Pendleton. The effects of urbanization on stream hydrology are well-documented (USEPA 1997, McMahon *et al.* 2003, Riley *et al.* 2005). The increased amount of impervious surface area around watersheds will increase the magnitude and duration of water flow and the number of extreme flow events. Water runoff from domestic uses can significantly increase aseasonal and year round water flow. In turn, these altered runoff patterns affect channel morphology and riparian habitat, typically changing ephemeral systems to perennial systems and creating deeper entrenched channels with faster water flow. This may directly reduce the availability of shallow pools required for arroyo toad breeding as well as support the successful colonization of many aquatic non-native predators that require permanent or near permanent water (Riley *et al.* 2005).

Invasion by non-native species is a major cause of biodiversity loss in our few remaining native habitats. Many of the invasive species in our area are deliberately brought in for landscaping, agriculture or other human uses. However, they frequently escape and become dominant, causing immense damage to natural plant and animal communities. Numerous studies have implicated invasives to be causes of local amphibian extirpations and significant species declines (i.e. Fisher and Shaffer 1996; see reviews by Kats and Ferrer 2003, Beebee and Griffiths 2005). Invasive species can harm amphibians by competing for resources, depredating native species, and carrying disease. Kats and Ferrer (2003) question whether native amphibians and invasive predators can co-exist in the long term. They propose that co-existence is a temporary condition that may only reflect a 'recent' invasive species colonization. They predict that it is only a matter of time, after the introduction of invasive species, that amphibian populations are reduced to such low numbers that they will ultimately disappear.

The non-native aquatic species documented in MCBCP thrive in areas with increased water flow, depth, and longevity. These species (catfish, bass, green sunfish mosquitofish, crayfish, and bullfrogs) are all known to prey upon amphibian eggs, larvae, and/or adults (Sweet and Sullivan 2005). The mosquitofish may be a significant predator of arroyo toad eggs (Grubb 1972) and alter the physical and biological characteristics of arroyo toad breeding pools (Hurlbert *et al.* 1972). Crayfish are opportunistic omnivores known to eat amphibian eggs and tadpoles (Fernandez and Rosen 1996, Saenz *et al.* 2003) and have been associated with declines in some native fish and amphibian populations (Warburton *et al.* 2003, Riley *et al.* 2005). Finally, bullfrogs are known to prey upon juvenile and adult toads in the wild and may be responsible for declines in several amphibian populations (Moyle 1973, Sweet 1993, Jennings and Hayes 1994, Griffin 1999).

The Santa Margarita River is the first and primary concern. This is where we have documented the majority of non-native species in all three years of monitoring. Since the discharge of water into the Santa Margarita drainage basin is guaranteed even in drought years (CWRMA 2002) and is predicted to increase into the future (Steinitz *et al.* 1996), we expect invasive aquatic species to be an ongoing problem in this watershed. Drying cycles typically result in local extirpation of many non-native aquatic species (Gasith and Resh 1999). These cycles represent the natural hydrology of the river in which the surface water dries by mid-September until the rainfall in late winter/early spring (Steinitz *et al.* 1996, USGS-WRD 2006).

The Cristianitos Creek sub-watershed in the northern part of the lower San Mateo watershed is also a concern with regard to urbanization and stream alteration. The northern portion of the Cristianitos Creek sub-watershed is currently being developed at a rapid rate and that will further increase with the proposed Orange County Southern Subregion Natural Community Conservation Plan (SSNCCP). At the northern border to MCBCP, this creek has already experienced an increase in hydroperiod from its natural ephemeral state and has become choked with aquatic emergent vegetation. We expect the discharge to continue to increase in this creek with the resulting threats of channelization, decreased water quality and invasive aquatic species.

A final concern is the proposed Foothill-south Toll Highway that would run adjacent and across lower San Mateo Creek and adjacent to Cristianitos Creek (Federal Highway Administration 2005). The impact of this highway is a threat to all arroyo toad populations along its path in Camp Pendleton. First, an unknown amount of individual toads and toad habitat (upland and wetland) would be destroyed upon construction and siltation from construction activities may cause substantial recruitment losses. The highway will alter the runoff patterns and therefore the hydrology of these creek systems, likely increasing overall discharge and stream flashiness. Impacts from vehicles would include road mortality, water contamination, and noise pollution. Road mortality in sections without barrier fencing could severely decrease survivorship. Barriers may also impede upland movements for overwintering toads, keep toads from certain habitats, and result in increased energy expenditures for toads moving farther distances to use underpasses. However, we expect that their positive impacts in reducing road mortality would outweigh the negative. The proposed wildlife corridors could become population sinks due to potential high predation pressures at these bottlenecks. Pollutants from vehicles, such as trace metals, hydrocarbons, and lead, could significantly reduce water quality, to which amphibians are especially sensitive. The call of the male arroyo toad is a soft high-pitched trill that would be very difficult, if not impossible, to hear above traffic noise. This would significantly decrease the probability of females in finding males for mating. In addition, road and vehicle lights are likely to affect toad behavior, although this has yet to be studied. According to the proposed foothill-south location, we estimated that this road would negatively affect at least 9 km or 10% of the total arroyo toad population on base. It is unknown whether the arroyo toad populations will be able to persist with these cumulative impacts in the long term.

Recommendations

Management:

Management recommendations address our future concerns as well as ongoing habitat and species management practices.

1. Continue eradication efforts of non-native aquatic species, particularly crayfish and bullfrogs in the Santa Margarita River, which are suspected of having the greatest impact on arroyo toad populations. This effort would involve active removal of these predators. We suspect that crayfish, overwintering bullfrog tadpoles, and bullfrog adults would be easiest to control during the late summer or fall, when deeper perennial pools become smaller and more isolated.

2. Continue eradication efforts of non-native plant species, particularly those that alter the natural hydrology of the arroyo toad occupied watersheds such as giant reed and tamarisk. This is expected increase available habitat for the arroyo toads by opening up the vegetation allowing for toad movement. By destabilizing stream banks, restoration of natural stream flow dynamics on which the toad is dependent should occur. Removal of watercress may be needed in the future as the river becomes perennial.

3. Beaver dams were documented on the upper Santa Margarita in 2003 and 2005. These dams can increase water levels potentially resulting in a reduction of adjacent breeding pools and creation of suitable habitat for invasive aquatic species. These dams may also inhibit upstream and downstream movement of larvae and adult toads. Continuation of the exotic beaver removal program is recommended.

4. Investigate whether the pumping of ground water for agriculture, domestic, and industrial use is at sustainable levels. This may be especially important in the San Onofre and San Mateo watersheds where loss of surface water due to pumping may greatly reduce the hydroperiods for these ephemeral streams. As a result, this may result in lack of arroyo toad breeding and recruitment success in affected areas documented in the spring of 2000 in lower San Mateo Creek (Holland *et al.* 2001).

5. Continue to manage nighttime training activities in riparian areas during the early breeding season (February- April) to avoid and/or minimize direct trampling of active adult arroyo toads by vehicles and/or troops.

6. Continue to manage training activities in wet areas during the larval development period (March-July) to avoid direct take of arroyo toad larvae and juveniles. To minimize loss, if training activities cannot be avoided, we recommend confining training to small area(s) and to minimize activities on the immediate stream edges and banks where larvae and juveniles aggregate.

7. Avoid and/or minimize habitat loss of uplands, where adult toads over-winter, within a kilometer of known arroyo toad breeding areas.

8. Continue to educate MCBCP training personnel in the identification and basic biology of the arroyo toad. Stress that good environmental stewardship includes the avoidance of toads and their habitat when possible.

9. Support the creation of models and mitigation measures for the impacts of the Orange County Southern Subregion Natural Community Conservation Plan (SSNCCP), Santa Rosa plateau development and the proposed Foothill-south Toll Highway on the hydrology of the San Mateo watershed within the base.

10. Support the creation of models and mitigation measures for the impacts of the Western Riverside County Multiple Species Habitat Conservation Plan (MSHCP) and the North San Diego County MSCP Subarea Plan on the hydrology of the San Margarita watershed within the base, with special attention to shallow water habitat.

Protocol:

We recommend adding two components to the current field protocol:

1. Index of arroyo toad larval abundance. This measure is needed to 1) model any relationship between detection probability and abundance, and 2) to investigate the relationship between abundance and spatial distribution. An abundance index is quite challenging for toad larvae (tadpoles) because the number of tadpoles is not consistently related to number of adult breeding toads. This is due to a combination of high reproductive output and high rate of mortality. For example, a single clutch of between 2,000 to 10,000 eggs, can be represented by 1000 tadpoles after 1 week, 400 tadpoles after 2 weeks, and 10 tadpoles after 4 weeks, and so on. Therefore, raw counts of tadpoles may have little utility in estimating toad abundance. We propose adding the following measures to the day survey protocol to evaluate for use as an abundance index:

Total Count of tadpoles	0, 1-10, 11-25, 26-50, 51-100, 101-250, 251-500, >1000
Percent of Reach with tadpoles*	0, 1-10, 11-25, 26-50, 51-75, 76-100%
Percent of tadpoles: Early stage	0, 1-10, 11-25, 26-50, 51-75, 76-100%
Percent of tadpoles: Mid stage	0, 1-10, 11-25, 26-50, 51-75, 76-100%
Percent of tadpoles: Late stage	0, 1-10, 11-25, 26-50, 51-75, 76-100%

2. Swab a representative number of arroyo toad adults and larvae for chytrid fungus. This would be done yearly across all watersheds in order to monitor for disease outbreaks and mortality events. Samples will be sent to Dr. David Green, at the USGS National Wildlife Health Center in Madison, WI, for analyses.

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Appendix 1. Day Survey Protocol

Appendix 2. Night Survey Protocol