

**Arroyo Toad (*Anaxyrus californicus*) Life History, Population Status, Population
Threats, and Habitat Assessment of Conditions at Fort Hunter Liggett, Monterey
County, California**

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by
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COMMITTEE MEMBERSHIP

TITLE: Arroyo Toad (*Anaxyrus californicus*) Life History, Population Status, Population Threats, and Habitat Assessment of Conditions at Fort Hunter Liggett, Monterey County, California

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Abstract

Arroyo Toad (*Anaxyrus californicus*) Life History, Population Status, Population Threats, and Habitat Assessment of Conditions at Fort Hunter Liggett, Monterey County, California

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The arroyo toad (*Anaxyrus californicus*) is a federally endangered species found on Fort Hunter Liggett, Monterey County, California. The species was discovered in 1996 and was determined to occupy 26.7 km of the San Antonio River from approximately 2.4 km northwest of the San Antonio Mission de Padua, to the river delta above the San Antonio Reservoir. The construction of the San Antonio Reservoir dam in 1963 isolated this northern population of arroyo toads. Through time, the Fort Hunter Liggett landscape has changed drastically. The land was heavily grazed by cattle until 1991, which considerably reduced vegetation in riparian areas. Military training following acquisition of the land in 1940 far exceeded current allowable training. Fire was used extensively to reduce unfavorable vegetation, and as a result, extreme tree loss occurred through the ranges. Today cattle grazing is prohibited and military activity is restricted from riparian corridors. While riparian vegetation continues to recover in the San Antonio River, habitat for breeding arroyo toads has become less suitable. To improve conservation efforts and management of this endangered species, I have provided a thorough assessment of the life history of arroyo toads specific to Fort Hunter Liggett and identified the status and current threats to the population on the installation. I have also prepared a habitat assessment of the San Antonio River in the arroyo toad range, quantified habitat conversion, and identified areas that may no longer provide suitable breeding habitat for the species. The research conducted for this report is preliminary to restoration efforts that are inevitable to ensure recovery of the endangered species at Fort Hunter Liggett.

Keywords: arroyo toad, life history, habitat assessment, breeding habitat, restoration, Fort Hunter Liggett, San Antonio River.

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CHAPTER 1: Description of Target Species, Study Area, and Goals for the Study

Introduction

The arroyo toad (*Anaxyrus californicus*) is a federally endangered species that inhabits coastal and desert drainages within the regions of southern California and Baja California (US Fish and Wildlife Service 1999) (Figure 1.1). The species has been extirpated from approximately two-thirds of its range due to loss of habitat and hydrological alterations to stream systems as a result of dam construction and flood control (Jennings and Hayes 1994). Introduced species, such as bullfrogs (*Lithobates catesbeianus*) and green sunfish (*Leopomis cyanellus*), increase predation pressure and contribute to the decline of the species. In systems where arroyo toads occur, survival is impacted by recreational activities, such as off-road vehicle and excessive foot traffic, water diversion or degradation from agricultural practices, channel stabilization from exotic plants, and cattle grazing (US Fish and Wildlife Service 1999).

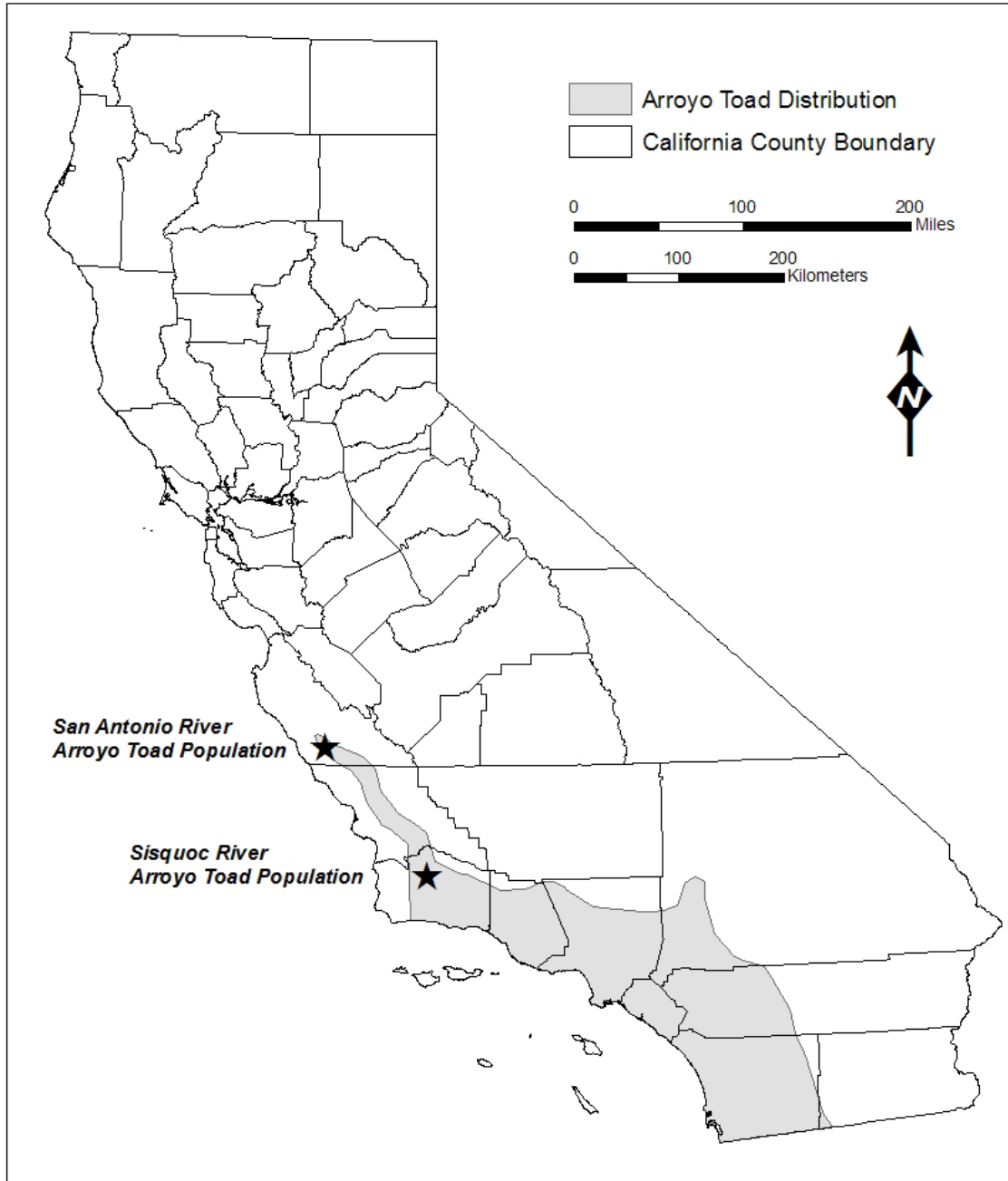


Figure 1.1: Arroyo toad distribution in California.

In 1996, arroyo toads were discovered at Fort Hunter Liggett (FHL) in Monterey County, California in the San Antonio River and were later determined to occupy 26.7 km of river from approximately 2.4 km northwest of the San Antonio Mission downstream to the alluvial floodplain above the San Antonio Reservoir. This isolated population

occurs at the northernmost edge of the species range (Figure 1.1). The next extant population is in the Sisquoc River in Santa Barbara County approximately 150 km to the south (US Fish and Wildlife Service 1999). Arroyo toad museum specimens were collected from the Salinas River in Santa Margarita, San Luis Obispo County in 1936 (Miller and Miller 1936), however occurrence of the species in that county has not been documented since (US Fish and Wildlife Service 1999).

Species Account

Adults are 5-8 cm in length from snout to urostyle (Figure 2.1 a). The dorsum is rough in texture and is generally light tan to olive in color (variable based on dominant substrate) and the vent is pale or white and lacks markings (Stebbins 1985). A v-shaped bar extends across the eyelids. The parotid glands are oval. Upon hatching, larvae are jet black and become dark to lightly mottled with age (Figure 2.1 b-c). The venter is pale or white without markings and the tail is banded. Newly metamorphosed juveniles are approximately 12-15 mm, resemble adults in appearance, and are heavily cryptic (Figure 1.2 d) (Sweet 1992).

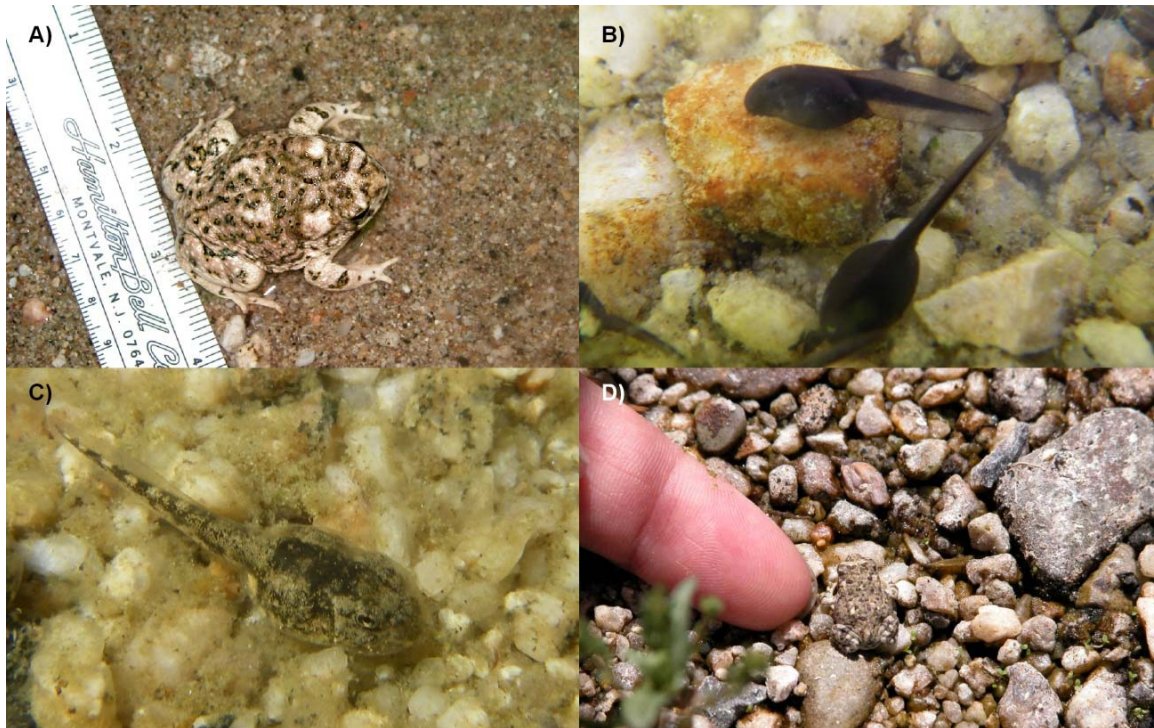


Figure 1.2: Fort Hunter Liggett arroyo toads: A) adult, B) newly hatched larvae, C) maturing larva, D) newly metamorphosed juvenile.

Arroyo toads favor seasonal systems that experience winter scouring of vegetation and that are often dry during late summer and fall months. Arroyo toads are nocturnal, forage and burrow in open floodplains and terraces, and breed in slow moving or pooling shallow water in areas open to the sky and with little emergent vegetation. The species is relatively sedentary and is not known to travel great distances over open terrain in search of new systems (Sweet and Sullivan 2005).

Breeding occurs in the spring, and is signaled by male advertisement for females. Vocalizations generally occur from about one hour past sunset to midnight. Adult males vocalize in streams in areas of shallow water typically with a gently sloping sand bank. The call is a one-note trill that lasts several seconds. After locating a male of choice, a gravid female, stimulated by amplexus, will deposit a single, double-stranded

egg mass in the shallow water (< 10 cm). Females breed once per season whereas males will breed multiple times as opportunity provides. Larvae hatch 3-5 days after oviposition and remain congregated along the water's edge in shallow water. As the larvae develop, they begin to use algal mats or detritus in deeper water for cover. After metamorphosis, juveniles remain close to water, but begin to burrow in sand within weeks. By early fall, most arroyo toads disperse into the uplands and spend most of the winter burrowed underground, emerging every few days to hydrate and forage (Sweet 1992).

Study Area

FHL is an US Army Combat Support Training Center located in southern Monterey County, California, approximately 37 km southwest from King City and 72 km northwest of Paso Robles. The Los Padres National Forest borders the installation to the north and west, and Jolon and Lockwood Valley border the installation to the east. FHL encompasses nearly 66,000 ha of the Santa Lucia Mountains. Vegetation communities include foothill pine (*Pinus sabiniana*), valley oak (*Quercus lobata*), chamise (*Adenostoma fasciculatum*), interior live oak (*Quercus wislizeni*), and California annual grassland. Two major river valleys traverse the installation from the northwest to the southeast: the Nacimiento and the San Antonio. The elevation ranges from 237 m at the San Antonio Reservoir to 1141 m at Alder Peak.

The climate at FHL is Mediterranean; winters are cool and wet, and summers are hot and dry. Annual precipitation is highly variable. July through June precipitation totals from 1987 to 2007 ranged from 18 cm (2007) to 117 cm (1998). The mountainous area on the western boundary generally receives twice as much rainfall as the river valleys. January and February are typically the most precipitous months. Summer daytime temperatures average 31-35° C with highs often exceeding 38° C, while winter days

average 15-18° C with lows often below freezing. July and August are typically the warmest months, while December and January are typically the coldest months.

Cattle ranching was the primary land use of FHL lands since the establishment of Mission San Antonio de Padua in 1771. FHL continued to lease land for grazing until 1991. Other agriculture was introduced to the valley bottoms by Early Americans in the mid to late 1880's, as was mineral and rock mining (Mellini and Seavey 1979). In 1940, the land was purchased from William Randolph Hearst and other private land owners to serve as a training installation for World War II troops. The installation continues to provide training for the 40th Mechanized Infantry Division of the California Army National Guard, Reserve units from several branches of the Armed Forces, and active components of the Army Rangers, Special Forces, Navy Seabees, Marines, and other federal, state, and local government agencies.

The 26.7 km of the San Antonio River that arroyo toads occupy is a 5th order stream. The river varies from narrow, cobble courses to wide, alluvial floodplains. The channel substrate is predominantly sand and gravel, with periodic exposures of sandstone bedrock. The bank vegetation is patchy to dense and is dominated by Fremont cottonwood (*Populus fremontii*) and mixed willow (*Salix spp.*) species. Discharge can exceed 280 m³ per second during winter storm events. Base flow is below 3 m³ per second during the spring. Much of the river dries or flows underground during summer and fall months (USGS Station 111449900 data).

Investigations

The goal of my research was to examine the life history of arroyo toads in the northern portion of their range and investigate the potential threats to population persistence for this endangered endemic species.

In Chapter 2, I investigate the behavioral, developmental, and environmental characteristics of arroyo toads on FHL and identify disparities with southern populations. Building a life history account of arroyo toads specific to FHL is important for installation conservation and habitat management efforts, and can be used to guide efforts attempting to document the species in its historic range in San Luis Obispo County. I also estimate total suitable breeding habitat at FHL, how it has changed since discovery of the species, and current threats that may be impacting the population and its habitat. This essential information is vital to recovery efforts of the endangered species at FHL.

In Chapter 3, I investigate habitat conversion within the range of arroyo toads in the San Antonio River and its relation to loss of oviposition sites on FHL. Over the past two decades, many reaches of the river have been altered by encroaching riparian vegetation, stabilizing the channel and reducing available shallow pools necessary for arroyo toad breeding activity. I examine aerial imagery to assess stream qualities and habitat of the river through military ownership of the land, and investigate potential environmental and anthropogenic influences that may have impacted the stream system. I use satellite data to quantify loss of bare ground and conversion to dense riparian vegetation, and identify candidate areas for restoration. Because of the narrow distribution and the limited breeding habitat of this isolated population, there is a need for information on how human activities influence critical habitats and either increase extinction risk or decrease likelihood of recovery.

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CHAPTER 2: Arroyo Toad Life History, Status, and Population Threats Specific to Fort Hunter Liggett, California

Abstract

The federally endangered arroyo toad (*Anaxyrus californicus*), which inhabits the San Antonio River at Fort Hunter Liggett in Monterey County, California, has adapted to environmental conditions that may be unique to its northern range. Formation of shallow pools and increased nightly temperatures in late April initiates commencement of breeding. Metamorphosis of larvae occurs as the system dries in July. Juveniles and adults combat extreme summer heat and lack of humidity by taking refuge in abundant herbaceous and riparian vegetation along stream margins. However, some environmental conditions may be detrimental to the population. Increased bank stabilization as a result of encroaching riparian vegetation has created incised channels in some areas of the San Antonio River, degrading suitable breeding habitat for arroyo toads. Introduced bullfrogs (*Lithobates catesbeianus*), which predate arroyo toads, and American beaver (*Castor canadensis*), which exacerbate vegetation encroachment and bank stabilization through dam construction, are both common in the system. These species profit from the habitat conversion and compromise recovery of arroyo toads at Fort Hunter Liggett. Appropriate habitat restoration and management is necessary for the installation to improve conservation of this endangered species.

Introduction

The arroyo Toad (*Anaxyrus californicus*) is a federally endangered species that inhabits coastal and desert drainages from Fort Hunter Liggett (FHL) in southern Monterey County in California to northwestern Baja California in Mexico (US Fish and Wildlife Service 2001). The species was discovered on FHL in 1996 and determined to

occupy 26.7 km of the San Antonio River from approximately 2.4 km northwest of Mission San Antonio de Padua to the river delta above the San Antonio Reservoir. Suitable habitat for arroyo toads was not located in any other stream system on FHL (Clark 2000).

Previous to the discovery of arroyo toads at FHL, the northernmost population occurred in the Sisquoc River in Santa Barbara County, approximately 150 km southeast of FHL. Three museum specimens were collected from the Salinas River Basin near Santa Margarita in San Luis Obispo County on June 12, 1936 (Miller and Miller 1936), however the species has not since been detected in the county (US Fish and Wildlife Service 1999a). The arroyo toad population at FHL may have once extended to the Salinas River but the construction of the San Antonio Dam in 1963 has isolated the population, likely contracting the extent of the range considerably.

FHL was established in 1940 to serve as a training site for World War II. Prior to the acquisition of the property, the land had been primarily used for cattle grazing. Training activity during the 1940's and 1950's far exceeded current allowable use. Much of the landscape was burned and extensive erosion, vegetation loss, and off-road vehicle traffic is evident in aerial photographs. FHL continued to lease land for cattle grazing until cessation of the program in 1991. Today military maneuvers are prohibited in the San Antonio River channel. All projects and activities that may negatively impact natural resources require review and clearance from the Environmental Division at FHL (FHL 1996). Upland areas of the San Antonio River are typically used for bivouac or live-fire range activities. Annual burning of the Multi-Purpose Range Complex is conducted during spring months to reduce incidence of wildfire that may escape into the riparian zone of the river. The FHL arroyo toad population is monitored annually as outlined in the endangered species management plan for the installation (Hancock and Clark 2004).

Through recent years, I have discovered a few yet significant anomalies characteristic of the FHL arroyo toad population. To improve management and protection of the species, I have compiled a life history account of the arroyo toad population specific to FHL based upon population monitoring and other related studies conducted since the discovery of the species in 1996. This compilation will not only benefit the installation, but may provide supplemental species information for other arroyo toad populations in drainages with similar climate and precipitation, as well as provide guidance for survey efforts attempting to document arroyo toads in the historic range of San Luis Obispo County. In addition, I have outlined current threats to the FHL population and provided direction to assist recovery efforts of the endangered species on the installation.

Study Area

FHL encompasses nearly 66,000 ha of the Santa Lucia Mountains in southern Monterey County. The San Antonio River enters the installation near the northwest boundary and empties into the San Antonio Reservoir in the southeast portion of the installation. The 26.7 km section of the river in which arroyo toads occupy transverses the wide plain of the San Antonio River Valley as a 5th order stream, and comprises intermittent sandy channels and sand bars with low elevation and sandy terraces adjacent to and between braided channels. The width of the floodplain ranges from 80-600 m, yet the width of the active river channel averages 10 m during spring months. The flow of the San Antonio River is seasonal, with surface water present primarily in winter and spring. During the fall, most flow continues underground, however many portions of the river remain perennial. The elevation of the river in the arroyo toad range is 238-317 m. The riparian vegetation canopy is predominately Fremont cottonwood (*Populus fremontii*) or mixed willow (*Salix spp.*) species, and the understory comprises

mule fat (*Baccharis salicifolia*), mugwort (*Artemisia douglasiana*), California rose (*Rosa californica*), and California blackberry (*Rubus ursinus*).

The climate at FHL is characterized as Mediterranean, with cool, wet winters and hot, dry summers. The average rainfall from 1960 to 2007 is 49 cm, yet annual precipitation is highly variable. In the past ten years, total rainfall has ranged from 18 cm (2007) to 117 cm (1998). The average daytime temperatures range from 15-18° C in the winter to 31-35° C in the summer. It is common for summer days to exceed 38° C and for winter mornings to drop below freezing. July and August are typically the hottest months, and December and January are typically the coldest months. Water discharge in the San Antonio River averages 8.5 m³ per second during the winter months and often exceeds 56 m³ per second during storm events. The river drops below 3 m³ per second during early spring months, then flows underground for much of its length during the summer and fall (USGS Station 111449900 data).

Surveys conducted for this life history compilation encompassed the entire FHL range of arroyo toads, including upland terraces and adjacent tributaries (Figure 2.1).

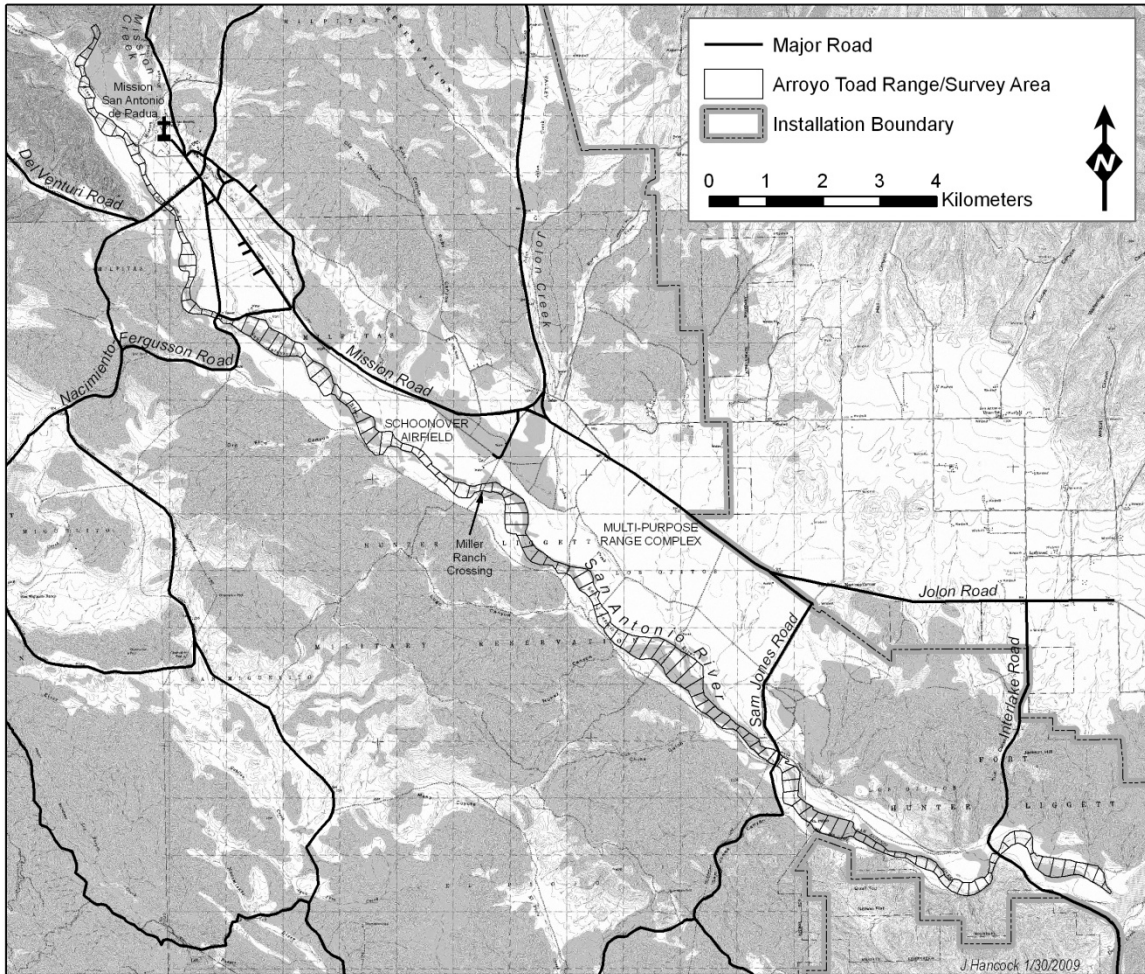


Figure 2.1: Arroyo toad range on Fort Hunter Liggett, subdivided by 200-m survey sections.

Methods

The information provided in this report was compiled from annual arroyo toad population monitoring and other related studies conducted on FHL from 1997 through 2008. Initial surveys, following the discovery of arroyo toads during Land Condition Trend Analysis surveys in 1996, were directed towards defining the population distribution. Surveys for calling males were conducted in 1997 under the lead of Karen Swaim at 7 sites along the San Antonio River and one site along Jolon Creek, a tributary

to the San Antonio River. Surveyors visited each site 1-4 times from March 20 to April 18. Surveys began at least one hour past dusk and lasted 30 to 60 minutes. Surveyors walked stable grassy banks counting all chorusing arroyo toads.

In 1998, Jones & Stokes Associates, Inc. were contracted to determine relative abundance and reproductive success of arroyo toads at FHL (Jones & Stokes 1999). Surveys were conducted 1-3 times at nine locations along the San Antonio River and two locations along Mission Creek, a tributary of the San Antonio River. Surveys were conducted between May 26 and July 2 and included nighttime surveys for calling males, daytime surveys for signs of breeding (i.e., presence of eggs or larvae), and repeated visits to oviposition sites to determine clutch success. Surveys were conducted following the guidelines provided by the United States Fish and Wildlife Service (USFWS 1995).

From 1999 to 2008, FHL staff and contracted biologists continued annual monitoring of arroyo toads in the San Antonio River following guidelines provided by the USFWS (1999b). Multiple surveys for calling males were conducted in April and May of each year, and were followed by surveys for oviposition sites May through July. In 2000, the 26.7 km arroyo toad range within the San Antonio River was subdivided into 200-m segments used for delineation of surveyed areas. Survey sites for calling males fell upon segment boundaries and breeding pool surveys were focused on the adjacent upper and lower 200-m segments (Figure 2.1). Inconsistencies between oviposition sites and male calling locations prompted an intensified focus on day surveys for oviposition sites in 2003. In 2004, habitat assessments of each surveyed 200-m segment were initiated which included a classification system for breeding suitability, mapping of fall flowing and pooling waters, and documentation of beaver activity. In 2008, development of larvae at 6 oviposition sites was tracked at least once a week from hatching through metamorphosis.

Most surveyed segments were selected at random each year, although many segments were specifically chosen in relation to information needed for installation projects or activities. Surveys for calling males were conducted at least one hour past sunset and surveyors remained at a distance in which chorusing arroyo toads were audible, yet undisturbed by human presence (50-300 m). Total numbers of calling males were recorded at survey sites each night. Surveys for oviposition sites began no earlier than two weeks following the first chorusing male of the year. Most surveyed segments were visited once, although beginning in 2006 some oviposition sites were revisited in an attempt to document larval development and success. Surveyors walked slowly upstream in water deeper than 0.1 m or on stabilized banks searching for arroyo toad egg masses or larvae. Beginning in 2002, oviposition sites were documented in a geographical information system (GIS) and stored with pool and habitat data. Bullfrog (*Lithobates catesbeianus*) and American beaver (*Castor canadensis*) dam locations were also maintained in a GIS. Numerous photographs were taken of developing larvae, breeding pools, and habitat.

In 2002 Nancy Sandburg was permitted and funded by the USFWS to conduct radio-telemetry tracking of arroyo toad movement at FHL with assistance from FHL contracted biologists. The study area was located between Del Venturi Road and Miller Ranch crossing and encompassed 6,900 linear m of the San Antonio River. Surveys were conducted eight times from April 4 through June 14 and included a daytime search for oviposition sites and a nighttime survey for calling males. Captured adult arroyo toads were tagged with a passive integrated transponder (PIT) manufactured by AVID Microchip ID Systems, Incorporated. Surveys and handling of arroyo toads were conducted in accordance to USFWS protocol and Section 10(a)(1)(A) permits under the Endangered Species Act (1973). No animals were fitted with radio telemetry devices. A

final report for survey activities and results was submitted to the USFWS and FHL (Sandburg 2004).

In 2005, FHL staff and contracted biologists monitored the earthquake retrofit of Sam Jones Bridge under the USFWS Biological Opinion 1-8-04-F-21. Construction began August 1 and concluded November 4. Biologists were on-site during all ground moving and vegetation clearing activities. Monitoring included two daytime and three nighttime pre-activity surveys, and daily morning and weekly nighttime site clearing during construction. A total of 6 adult and 53 juvenile arroyo toads were captured and relocated to areas predetermined to support the species, and at an appropriate distance from the project area to preclude return to the site. Extensive tracking of juvenile and adult movement was accomplished through morning surveys, which offered insight to burrowing habits and dispersal efforts. A final report was submitted to the USFWS following conclusion of the retrofit project (Hancock 2006).

In 2008, FHL contracted biologists monitored the earthquake retrofit of Nacimiento Bridge under the USFWS Biological Opinion 1-8-07-F-11R. Construction activities began August 11 and concluded December 19. Biologists were on-site during all ground moving and vegetation clearing activities. Monitoring included five daytime and three nighttime pre-activity surveys, and daily morning and weekly nighttime site clearing during construction. A total of 19 juvenile arroyo toads were relocated to areas predetermined to support the species, and at an appropriate distance from the project area to preclude return to the site. A final report was submitted to the USFWS following conclusion of the retrofit project (Hancock 2009).

In addition to regular monitoring, all incidental sightings of adults have been recorded in a GIS. Other monitoring during which valuable documentation of arroyo toad behavior was obtained included monitoring of: active unimproved water crossings (2001-2008), vegetation clearing at the Del Venturi concrete crossing (2005), areas

following wildfire activity (2004 and 2007), Schoonover Airfield (2006), and petroleum spill clean-up at Miller Ranch crossing (2008).

Results

Habitat Features

The morphology of the San Antonio River in arroyo toad habitat varies from exposed sandstone and Monterey shale bedrock, with moderately entrenched banks, deep pools and dense canopy cover, to wide, sandy alluvial plains with braided channels and sparse, willow dominated riparian vegetation. Although arroyo toad oviposition sites have been documented from the uppermost portion of the 26.7 km range to the San Antonio Reservoir inlet, suitable breeding habitat is incongruous.

Suitable breeding habitat in the San Antonio River contains shallow water (< 30 cm) with low current velocity, and maintains surface water for a minimum of 3 months. Oviposition sites primarily occur on the margin of the active channel, in pooling water forming at stream margin, or in isolated pools. Oviposition sites contain sand or gravel substrates, and less often, cobble or bedrock substrate, have little to no emergent vegetation and little to no shade despite patchy to dense riparian vegetation on adjacent banks (Figure 2.2). Aquatic algae does not appear to be relevant to site selection, however as larvae mature, algal mats become ideal as escape cover. Breeding habitat is most abundant where the river channel is braided and the riparian vegetation is at mid-successional stage. In years of above-average precipitation, it is common for oviposition sites to occur in more vegetated and deeper water (higher water level in the river reduces available habitat). Oviposition sites are typically associated with a sand bar and/or a sandy terrace.

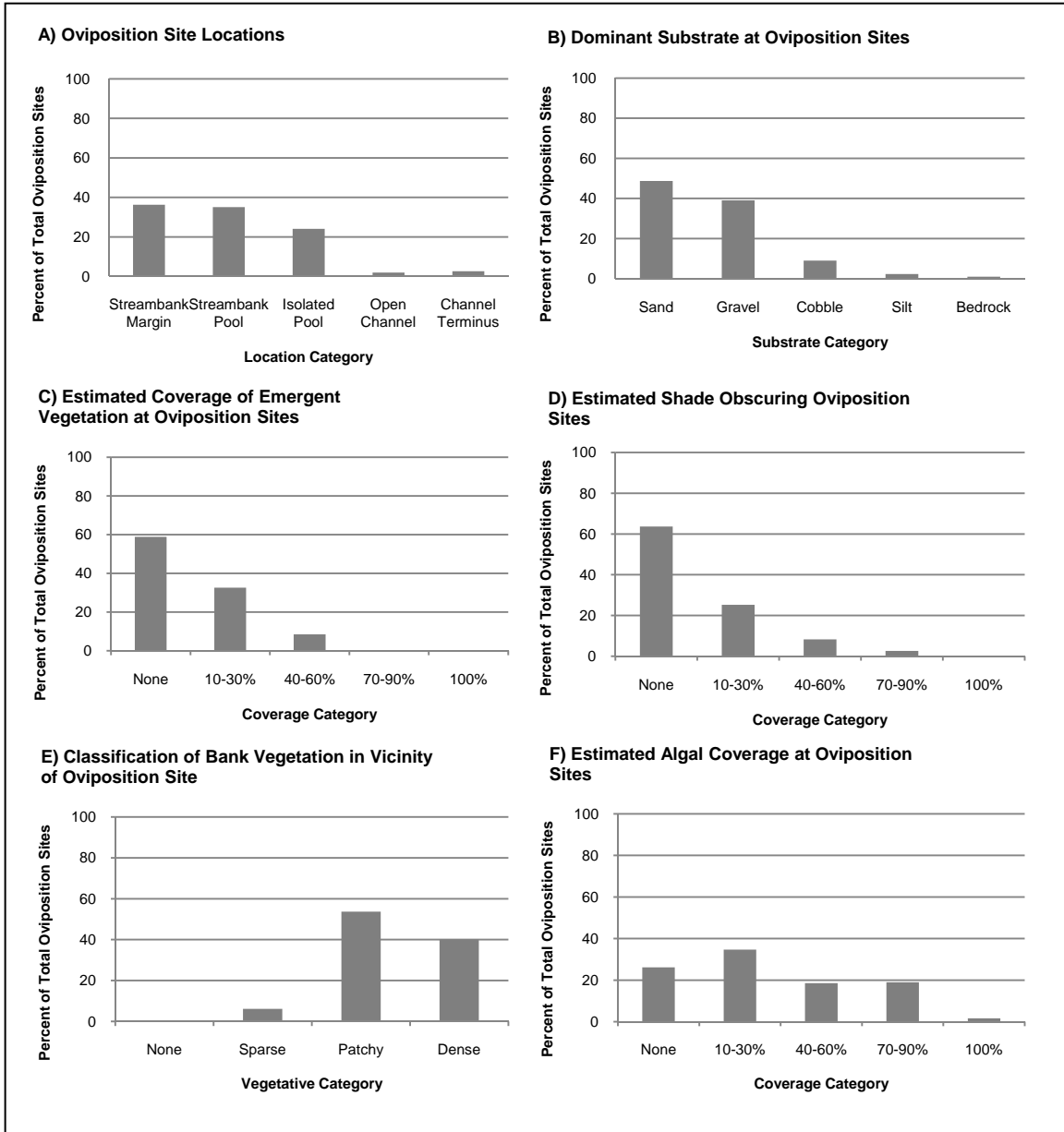


Figure 2.2: Percentage of surveyed arroyo toad oviposition sites in 2004-2008 exhibiting specific characteristics: A) location relative to stream channel; B) dominant substrate; C) estimated coverage of emergent vegetation ; D) estimated coverage of shade; E) classification of bank vegetation in vicinity; F) estimated coverage of algae.

Unsuitable breeding habitat in the San Antonio River lacks shallow pooling water and typically contains water year-round. The channel in these areas is often entrenched and lacks sinuosity. Bank vegetation is dense and encroaches into the active channel. Year round occurrence of predacious bullfrog and introduced beaver is supported in these areas. Exotic plants such as cattails (*Typha spp.*) may become dense and occlude banks to arroyo toad movement.

There are portions of the river in which breeding habitat suitability fluctuates with annual precipitation patterns, streambed scouring events, and fluvial deposits. These areas might contain secondary channels that provide ideal breeding habitat conditions in years with above-average rainfall, or areas that generally lack shallow pooling water except in years with below-average rainfall. These areas are often associated with sandy terraces and open floodplains ideal for foraging adults.

Adult Activity and Behavior

The arroyo toad breeding season at FHL is initiated by male vocalization, which typically begins late April when the river flow has decreased and shallow pools form. Oviposition generally occurs between the first week of May and mid June, peaking mid May. If nightly temperatures are unusually warm or if water levels have prematurely dropped (due to low precipitation) then males may be stimulated to call earlier. These conditions have not been documented to affect timing of oviposition. The duration of the breeding season is generally six weeks; deviations are attributed to a combination of winter precipitation and available forage for development of eggs in females. Breeding during years with below-average to average rainfall is most abundant and minimal during extreme drought (observed in 2007 following 18 cm of rain).

Male arroyo toad vocalizations are long, one-note trills which vary in pitch per individual and last 2-5 seconds. Vocalization intervals increase with proximity to

additional vocalizing males. The trill is distinctive and may be heard as far as 300 m away from its origin at FHL where noise pollution is minimal. Males are vulnerable to predators when vocalizing, and are hence sensitive to disturbance. Once disrupted, it may take several minutes for a male to resume calling. A significant drop in temperature or a rain event will subdue calling activity.

While it is common to locate oviposition sites incontiguous from sites where chorusing arroyo toads are detected, some males have been identified to exhibit site fidelity to their selected calling location. Five males identified with a PIT tag were found in the same location on multiple survey nights. This fidelity to breeding sites may extend beyond a single breeding season. In 2003 and in 2005 males were identified chorusing two days following a rain event that elevated the water level creating breeding habitat in two locations that were previously dry. Both locations were isolated occurrences of suitable breeding habitat, where adjacent stream channels were unfavorable for arroyo toads.

Foraging adults are rarely observed at FHL; open, sandy terraces are abundant providing unrestricted movement and potential for adults to forage without intraspecific competition. A total of 13 adults from 2001 to 2007 have been sighted outside of the active river channel. All sightings have been within 200 m of the water. By mid June, breeding adults retreat from the water. In 2002, the last observance of a mature adult was June 7.

The hot, dry climate at FHL results in high evaporation of soil moisture. Cool, damp soil ideal for burrowing occurs close to the waterline and under leaf litter in vegetated areas. In 2005, 2 adult arroyo toads were unearthed during vegetation clearing during the bridge earthquake retrofit project on August 2. The mid-successional vegetation was dense and comprised approximately six cottonwoods (*Populus fremontii*) less than 20 feet in height, many small willow clusters (*Salix lasiolepis*, *Salix exigua*),

mule fat (*Baccharis salicifolia*) and other herbaceous perennials. The adults were within 10 m of each other, and within 15 m of the water's edge. An additional five adults were found foraging in the 1.2 ha project site during monitoring surveys. Surveys earlier that year documented 5 arroyo toad oviposition sites 25-150 m upstream from the project location.

Larval Development

Arroyo toad egg strands are laid in shallow water (< 10 cm) that is generally free of emergent vegetation. Larvae typically hatch within 3 days and are immobile for an additional 2 days. At approximately 9 days, the larvae begin to disperse, though tend to remain in close proximity to their natal pool. Metamorphosis occurs within 60 days of oviposition. The rate of larval development may accelerate in extreme conditions; in 2006, larvae found in an isolated, solar-heated pool on bedrock were estimated to have achieved metamorphosis in less than 40 days.

Larvae feed on detritus material as well as carrion and slow moving aquatic insects as opportunity provides. They typically remain in shallow water until metamorphosis but will flee to deeper water or burrow in sand or algae to escape predation. Until larvae reach approximately 14 mm in length, larvae may have difficulty navigating through filamentous algae and are susceptible to desiccation if entangled as the water recedes. Yet once movement is no longer impeded by algae, large mats become an important source of cover.

Arroyo toads hatch as jet-black, gilled larvae approximately 3 mm in length. At 9 mm, the gills are absorbed. By 11 mm, the black becomes slightly mottled and gold barring is present on the tail. At 14 mm, the vent is light and tan patches appear at base of tail and mid dorsal-laterally. At 21 mm, the mottling is more extensive and the overall appearance of the larvae is olive to tan in color. By 24 mm, the black mottling is reduced

and concentrated on the dorsum and by 29 mm, remains as a single spot near the base of the tail. At 34 mm, the hind legs are visible from above and by 37 mm are functional. At this point the black is absent and a faint tan stripe appears between the eyes. From 39-43 mm, the hind legs become more developed, the body shape more defined, and the front legs erupt. At the onset of metamorphosis, the dorsum is mottled with white and dark spots, the cranial stripe is prominent, and tail takes on an orange hue as it is absorbed. Once metamorphosis is complete, juvenile arroyo toads have the coloration and markings of wet sand. With age, they lighten to the color of dry sand (Figure 2.3).

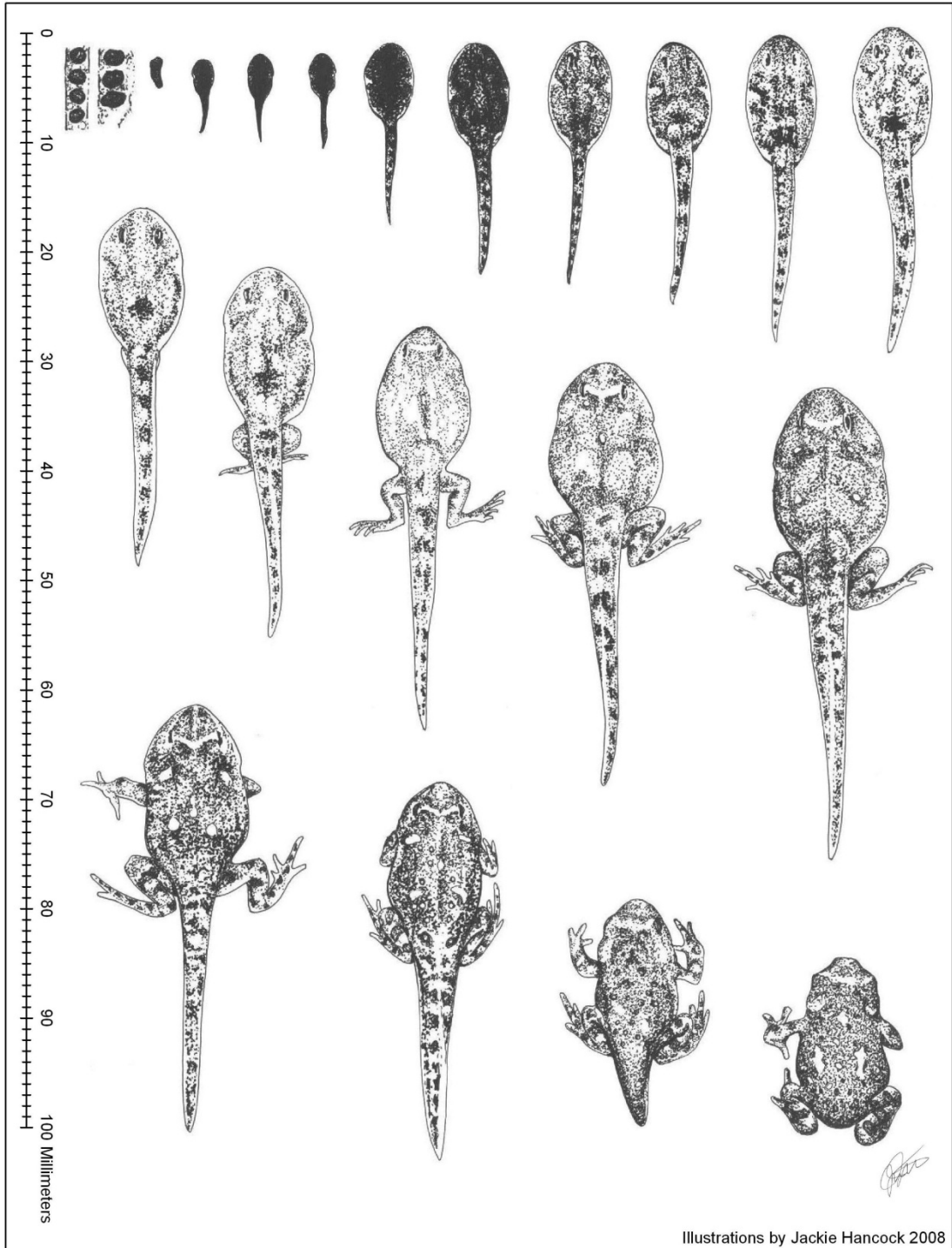


Figure 2.3: Illustration of Fort Hunter Liggett arroyo toad larvae from egg through metamorphosis.

Juvenile Activity

Metamorphosis typically begins mid June and is complete by the end of July. During the process of metamorphosis, juveniles will remain close to the water's edge and hide under drying algal mats or cobbles. Once complete, they disperse along the shoreline and seek refuge under bank vegetation. Within 2 weeks of metamorphosis, the juveniles are able to burrow into loose sand. In August diurnal activity is reduced with most active foraging occurring between 1000 and 1100 hrs. Juveniles will continue to burrow close to water in sandy, vegetated regions with minimal to no slope. By early September, the juveniles are entirely nocturnal and by mid September disperse from their natal grounds. They remain near the riverbank to forage and hydrate, but move higher into the riparian vegetation to burrow during daytime hours. General activity decreases substantially by the end of October.

Diurnal juvenile arroyo toads are highly susceptible to predation, and entire cohorts may be exterminated by foraging predators. Suspected predators at FHL include killdeer (*Charadrius vociferus*), Brewer's blackbird (*Euphagus cyanocephalus*), green heron (*Butorides virescens*), great blue heron (*Ardea herodias*), two-striped garter snake (*Thamnophis hammondi*), aquatic garter snake (*Thamnophis atratus zaxanthus*), giant water bug (*Abedus sp.*), wild turkey (*Meleagris gallopavo*), raccoon (*Procyon lotor*), opossum (*Didelphis virginiana*), and bullfrogs (*Lithobates catesbeianus*) which are also effective predators of adults (observed). Herbaceous bank vegetation, such as water speedwell (*Veronica anagallis-aquatica*), introduced white sweet clover (*Melilotus alba*), and cobbles serve as important cover for maturing juveniles. Dense herbaceous bank vegetation increases vital soil moisture and decreases soil temperature, which at FHL can reach temperatures in excess of 60° C on exposed sand. After dispersal, it is common to find juvenile tracks exiting and entering dense stands of riparian vegetation, even those bordered by dense thatch of yellow star-thistle (*Centaurea solstitialis*).

Population Status and Current Threats

Since surveys began in 1997, arroyo toads have been estimated to utilize 75% of the 26.7 km range for oviposition. Since the last comprehensive survey conducted in 2005, utilized habitat has been reduced to 61%. Most of the area not utilized by the species lies in the uppermost 5 km of their range; oviposition sites have not been detected in this region since 2004 (Figure 2.4). Natural riparian vegetation succession and encroachment into the stream channel is suspected to be the primary cause of this range reduction. Areas where reduced activity has been observed typically contain narrow, incised channels with little to no braiding and are often occluded by riparian vegetation. These areas are frequently shaded and deep on at least one side of the channel. Bank stabilization is prevalent, enabling increased riparian vegetation growth. Beavers are attracted to these areas and exacerbate vegetation encroachment by introducing willow cuttings into the stream channel. Beaver activity is common within the FHL arroyo toad range, however most dams outside of these channelized areas are breached by winter floods and have little impact on adjacent habitat.

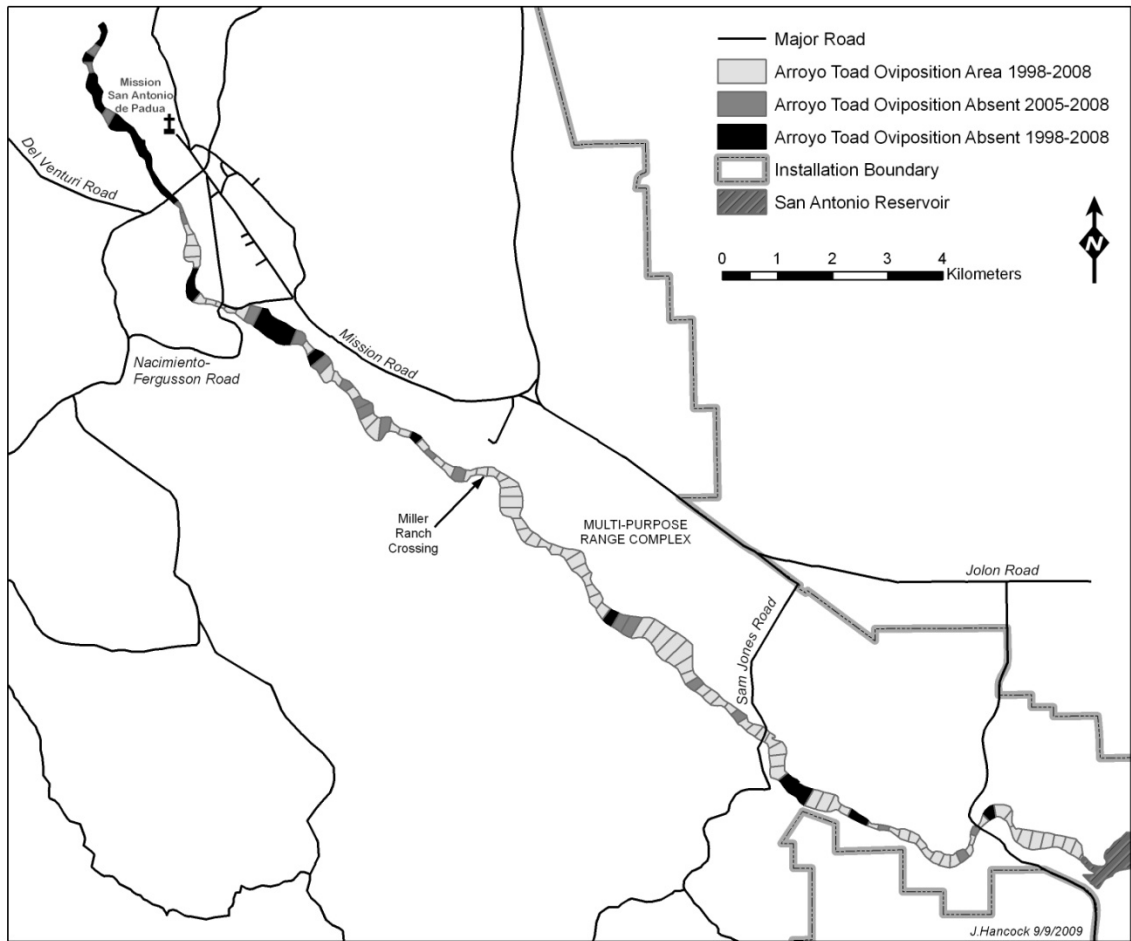


Figure 2.4: Arroyo toad oviposition areas on Fort Hunter Liggett.

Bullfrog predation is a serious threat for arroyo toads at FHL, particularly for vulnerable vocalizing males during the breeding season. Bullfrogs are common at FHL and their productivity and survivorship is facilitated by the narrowing and deepening of the active channel in the San Antonio River. Deep, shaded pools in the stream channel offer ideal breeding habitat for bullfrogs and increase the chance of larval survivorship through the summer and fall when water recedes. Bullfrogs are most prevalent in the upper region of the arroyo toad range. The San Antonio River retains 60% of linear surface water (flowing or pooling) in the 26.7 km range under extreme drought conditions (measured in 2007 following 18.5 cm of precipitation in the preceding rain

year). Based on this estimate of minimum perennial water, there is potential for overwintering bullfrogs to survive in more than half of the arroyo toad range.

The FHL arroyo toad population is most stable at the center of its range (Miller Ranch Crossing to Sam Jones Road), with productivity generally decreasing toward the periphery; habitat in northernmost portion of the range is marginally suitable for breeding, while highly suitable habitat in southernmost portion of the range does not always contain surface water sufficient for annual breeding.

Discussion

The arroyo toad population at FHL as described is similar to those described in other systems. What is unique about arroyo toads at FHL are timing and duration of breeding period and larval development. Arroyo toads throughout their range typically initiate breeding in February for coastal populations and late March to early April for montane populations, and continues through July (Sweet and Sullivan 2005); FHL breeding begins late April and concludes mid June. The larval development period for populations in the Los Padres National Forrest is 72-80 days (Sweet 1992) and 77-97 for Marine Corps Base Camp Pendleton Populations (Brehm et al. 2004); the FHL population is 55-60 days.

The breeding season for arroyo toads at FHL is restricted by environmental constraints that may not be present in other drainages supporting the species. Commencement of activity is dependent upon the timing of shallow pool production in the San Antonio River and appropriate nighttime air temperatures, and completion of metamorphosis is challenged by a drying river system. At FHL, the discharge maximum for egg strand and larvae survival is estimated to be 2 m³. Annual peak flow of the San Antonio River typically occurs in February; discharge decreases dramatically from March to April (USGS Station 111449900 data) and drops below 2 m³ mid to late April (Figure

2.5). While shallow pools are beginning to form at this time, ambient evening temperatures are increasing. Arroyo toads generally do not become active until nightly temperatures exceed 13° C (Sweet 1992); at FHL, average temperature at 2100 hrs steadily increase above 13° C by late April (Figure 2.6). Based on this data, environmental conditions are expected to be appropriate for breeding by the last week in April, which concurs with FHL survey results.

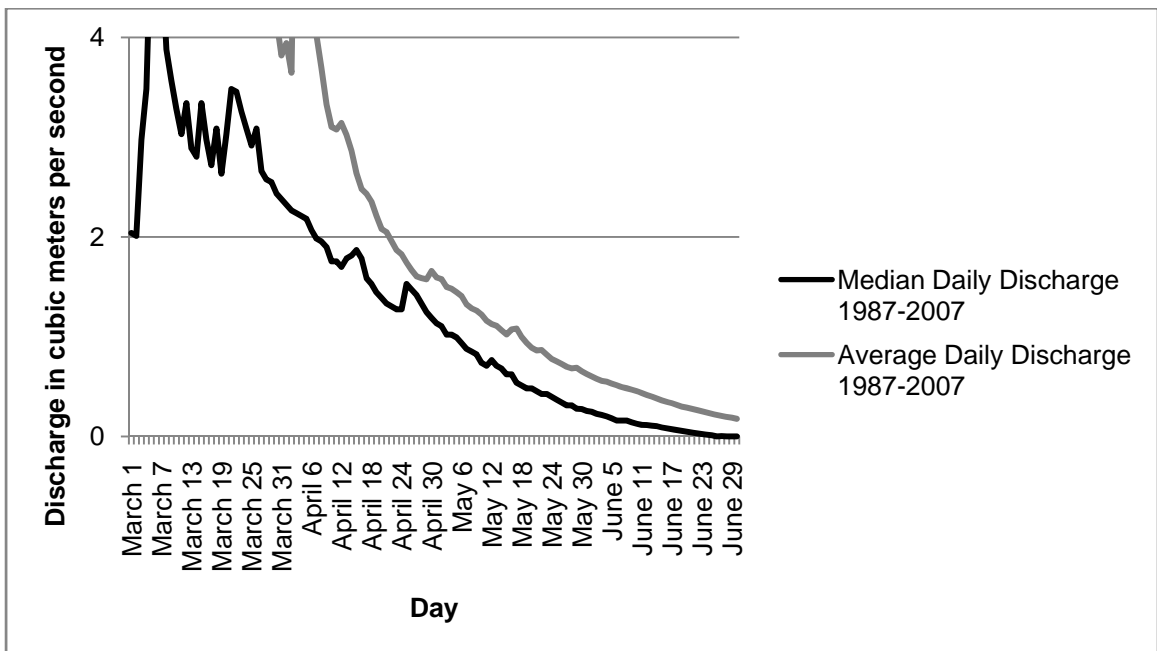


Figure 2.5: Median and average daily discharge for the San Antonio River at USGS Station 111449900 1987-2007.

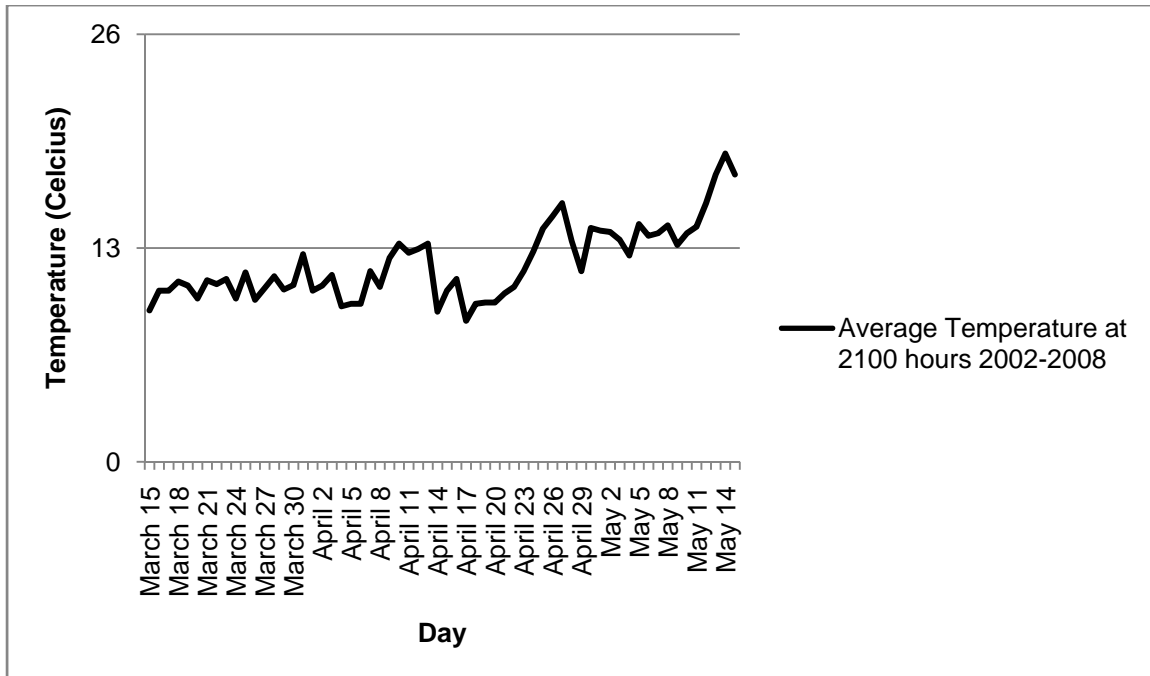


Figure 2.6: Average ambient temperature at 2100 hrs for Fort Hunter Liggett 2002-2008.

By late June, metamorphosis begins as surface flow ceases throughout much of the range. By August, most pools that are not supplied year round with surface water have dried. All arroyo toad larvae have typically completed metamorphosis by this point. Based on these constraints and timing of breeding, FHL has approximately 45-90 days of suitable habitat for developing larvae. It is conceivable that other arroyo toad populations subject to similar environmental constraints, such as in desert drainages, would respond with accelerated breeding seasons and larval development.

The riparian vegetation in the San Antonio River is much more extensive than described in other arroyo toad populations. At FHL, arroyo toads often breed in areas with isolated sand deposits amidst densely vegetated banks with deep, incised channels. Concentrated scat, which is a potential sign of burrowing activity (Sweet 1992), is often found within stands of sandbar willow (*Salix exigua*) or other mid-

successional riparian growth. While this relationship may be incidental, it is possible that arroyo toads at FHL seek these protective areas to combat desiccation. If this is a response to heat and humidity, then we may be able to extrapolate adult behavior based on studies conducted in inland populations where climate is similar. For example, we may anticipate estivation burrows and movement to be in closer proximity to the active river channel, such as reported by Ruben Ramirez (2000, 2001).

It is likely that arroyo toad behavior and development characteristic of FHL would be consistent with arroyo toads potentially inhabiting the historic range of the Salinas River in San Luis Obispo County, since climate, precipitation, and river structure is similar. The Salinas River is fed from headwaters in the mountains of eastern San Luis Obispo County and flows northwest into Monterey County, emptying into the Monterey Bay (Figure 2.7). The only dam on the river was built in 1941 establishing the Santa Margarita Lake (San Luis Obispo County Parks). It was in this region that the only arroyo toad museum specimens for the county were collected in 1936 (Miller and Miller 1936). Although the river experienced hydrological changes with the construction of the dam, areas of suitable habitat for arroyo toads is present through the system from the dam to the confluence of the Nacimiento River in southern Monterey County (personal observation). Outflow from the Nacimiento Reservoir and the San Antonio Reservoir (next downstream confluence to the Salinas), is regulated and the resultant hydrological regime is unsuitable for breeding arroyo toads downstream of these confluences. Within the area of potential habitat on the Salinas River, precipitation, discharge, ambient air temperature, and humidity are similar to that of FHL. The average annual rainfall for the Salinas River for the Paso Robles area (central in potential habitat) is 38.7 cm. Although average rainfall is less, distribution of precipitation parallels FHL (Figure 2.8). The same is true of average maximum temperatures for the area (Figure 2.9). Data collected from

a USGS station in Paso Robles (Station 11147500) indicates that discharge patterns and rates are similar for both systems (Figure 2.10).

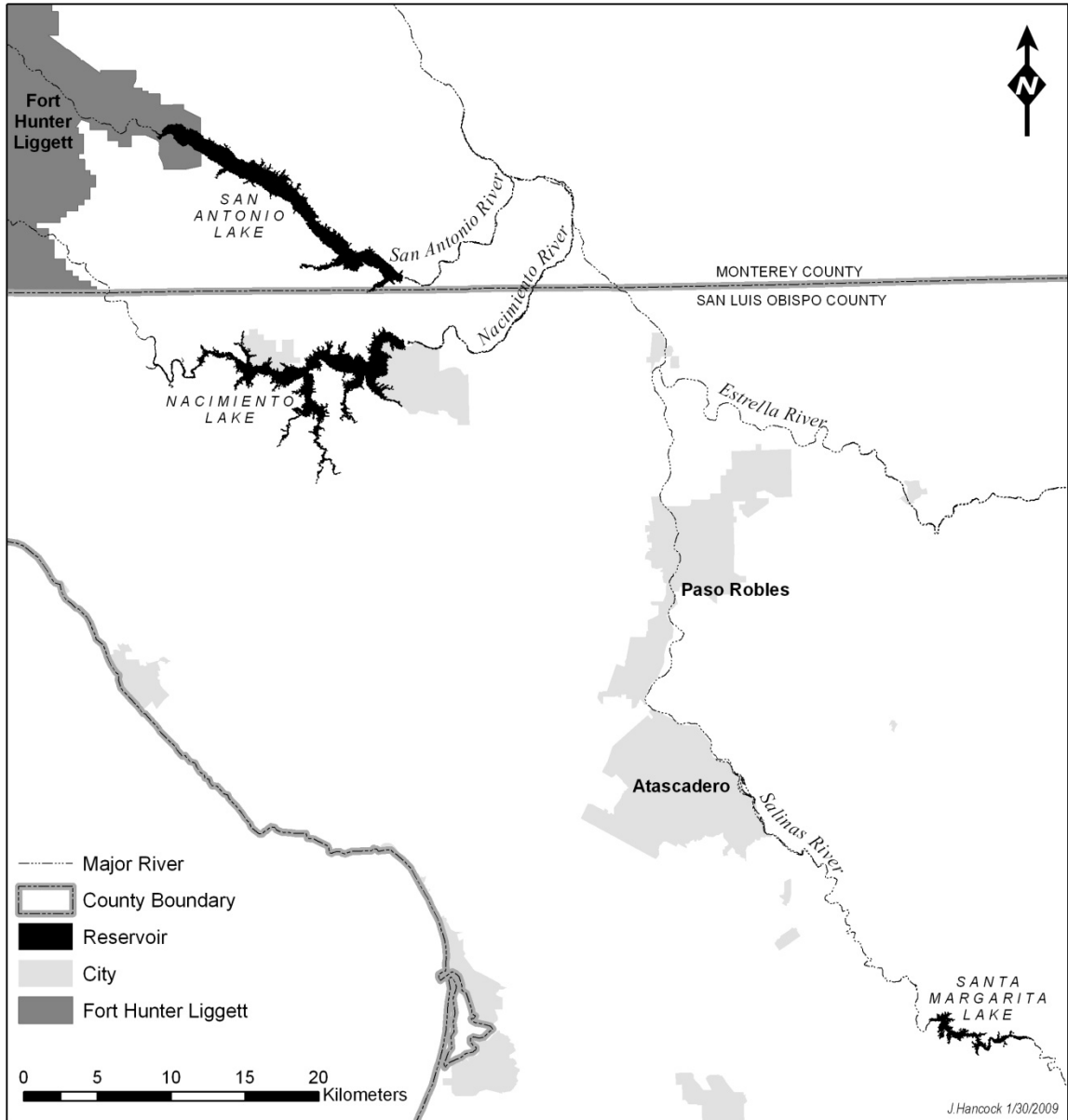


Figure 2.7: Salinas River in San Luis Obispo County.

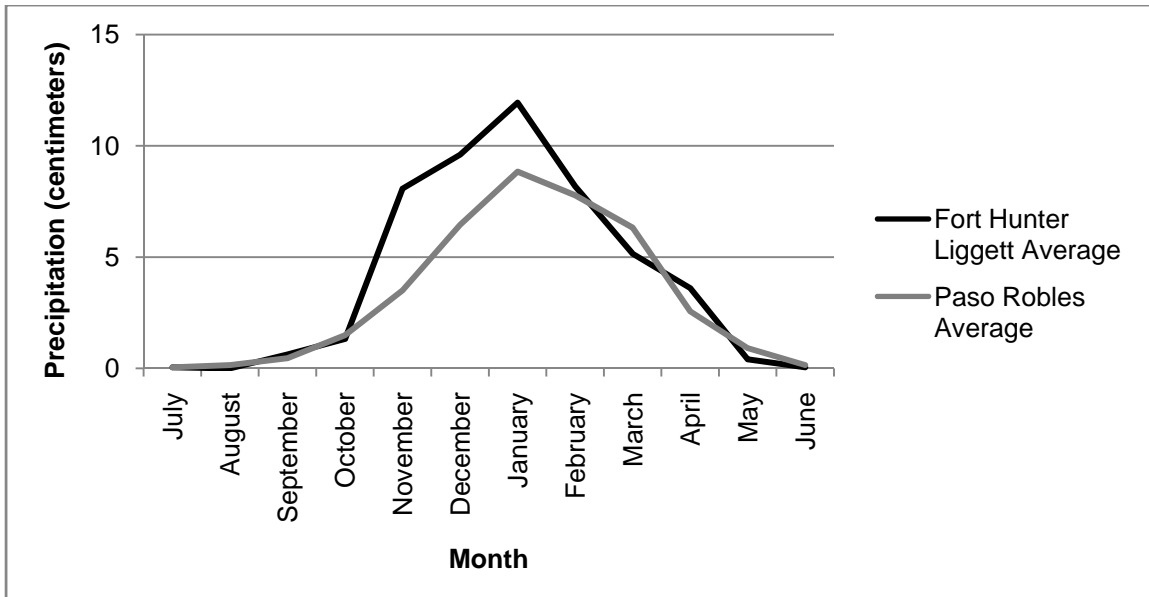


Figure 2.8: Average precipitation for Fort Hunter Liggett and Paso Robles.

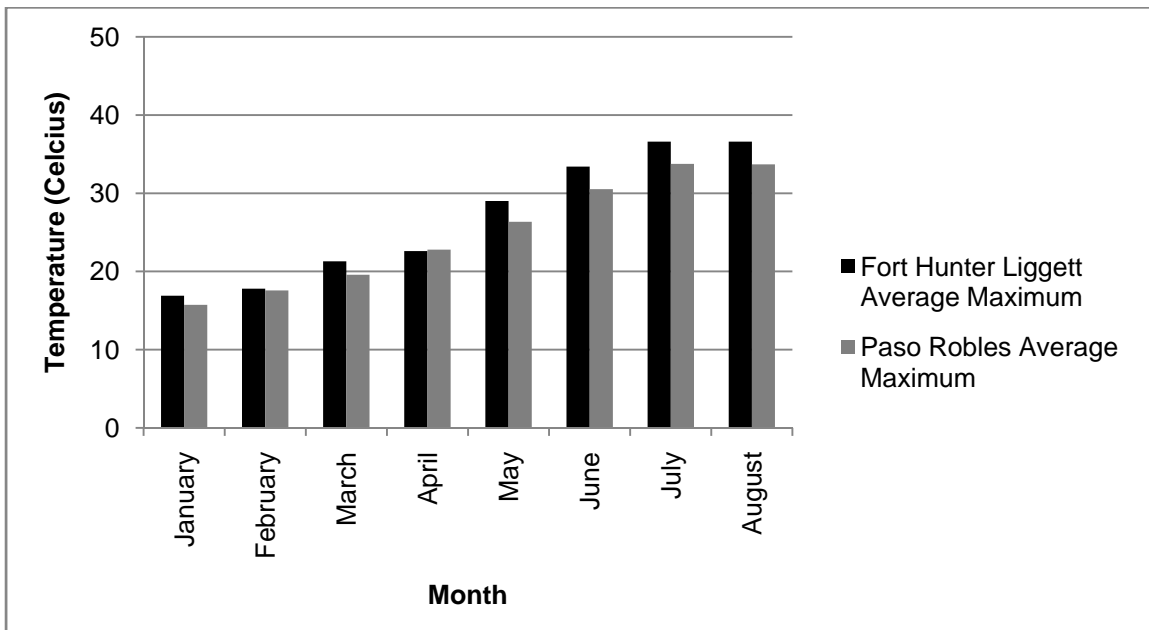


Figure 2.9: Average maximum temperature per month for Fort Hunter Liggett and Paso Robles.

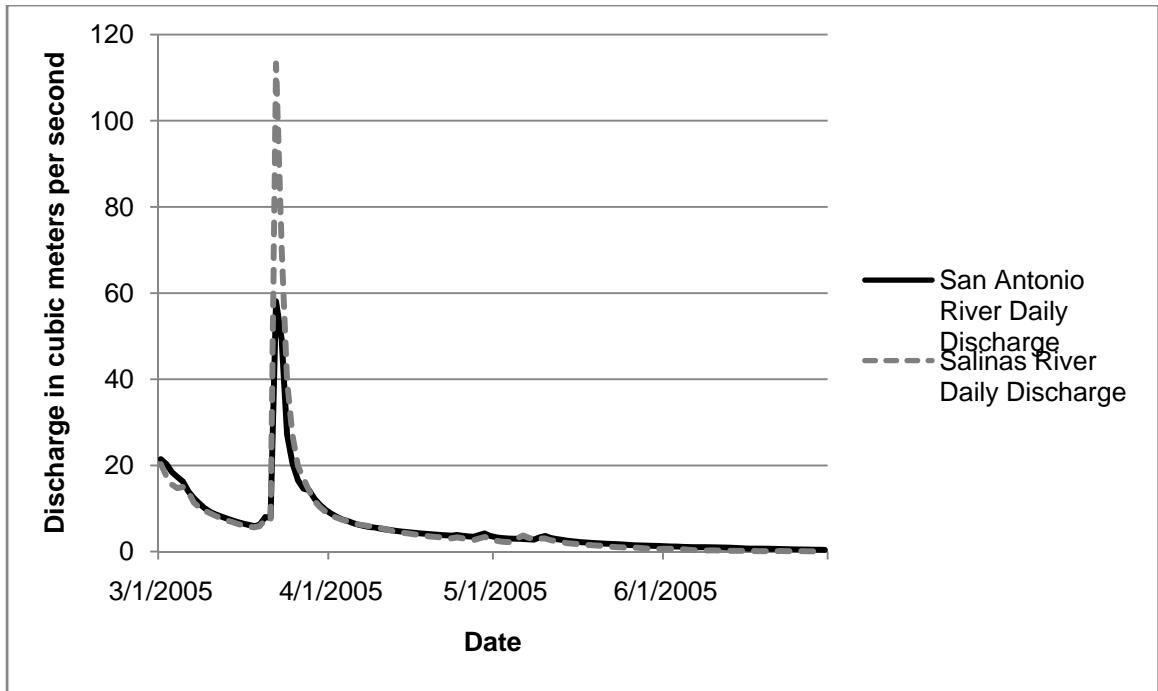


Figure 2.10: Daily discharge rates for the San Antonio and Salinas rivers in 2005.

Some tributaries to the Salinas River may have isolated suitable habitat, however most are heavily sedimented and only support surface flow for a few days; flow is sufficient in some years in the Estrella River, but not consistent enough to support more than an opportunistic satellite population (USGS Station 11148500 data).

Management Implications

The extensive surveying of arroyo toad breeding habits and larval development at FHL has provided installation with valuable information that will improve management and protection of the species. Defining the breeding season and larval development period in time allows for proper monitoring design and mitigation for projects that may potentially impact the species. However important data regarding adult habits and movement is lacking. We may extrapolate behavior exhibited by adults in other systems with similar climate and precipitation, but until further research is conducted at FHL,

definitive answers may not be available. A pit-fall trapping and or radio telemetry tracking study at FHL would provide the installation with this essential information.

While the information gained at FHL further expands the arroyo toad knowledge base and may be beneficial for other population managers, it is most advantageous for surveyors attempting to locate the species within its historic range in the Salinas River or its tributaries. It should be anticipated that potential populations will begin breeding late April and that adults may not be detectable past June. Noise pollution may interfere with detection of chorusing adults in urban settings. Arroyo toad larvae may use emergent vegetation or algae as cover, increasing difficulty of detection. Surveyors should assume accelerated larval development; a single clutch may complete metamorphosis by July and juveniles combating desiccation may no longer be detectable past this point. It is important to consider vegetated areas as potential breeding habitat as long as shallow pooling water is present and unobstructed by excessive emergent vegetation. It should be anticipated that adults will estivate in relatively dense vegetation. And most importantly, surveyors should acknowledge that entire populations may not breed during drought conditions. Efforts including these considerations will result in most reliable presence or absence determinations.

The arroyo toad population at FHL is fortunate not to be subject to many of the leading threats impacting other populations, such as recreational activities, development, and agriculture. However, the few threats that the population faces are severe, as evident by a reduction in the range of oviposition sites since 2005. It is imperative that FHL implement a restoration plan to slow, halt, or reverse breeding habitat loss to riparian vegetation succession. Bullfrog or beaver removal from the San Antonio is an arduous task that may be unachievable due to proximity and high number of thriving populations in other streams and reservoirs. However these species may be controlled or their impacts reduced indirectly through habitat management. Reducing channel

incision and improving sinuosity would relieve predation pressure of bullfrogs that thrive in the deep, shaded areas created in the stabilized stream. Established beaver dams not breached by winter floods should be dismantled to allow natural scouring and sedimentation of the channel to occur. Prior to the construction of the San Antonio Dam, the arroyo toad population may have been able to shift occupancy up- or downstream in response to adverse habitat changes. Now with a restricted range, the population can no longer accommodate stream stabilization and survivorship is compromised. Improving breeding habitat will greatly benefit arroyo toads at FHL and increase recovery potential for this endangered species.

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CHAPTER 3: Loss of Arroyo Toad Breeding Habitat at Fort Hunter Liggett and Investigation of Potential Environmental and Anthropogenic Influences Accelerating Habitat Conversion

Abstract

The federally endangered arroyo toad (*Anaxyrus Californicus*) has lost prime breeding habitat to vegetation encroachment and bank stabilization in the San Antonio River at Fort Hunter Liggett. It is estimated that the population currently uses 61% of the entire range for oviposition; 8% less than what was estimated in the past decade. Extreme vegetation loss in the riparian channel and floodplains occurred between 1949 and 1963, when military training was at its height. The hydrological impacts of this vegetation loss may have been masked by heavy cattle grazing and an impacted groundwater basin from irrigation in the valley, which inhibited vegetation growth in the San Antonio River. Since cessation of the grazing program in 1991, and recovery of the groundwater basin from change in agricultural practices, vegetation succession has proceeded and the channel is now moving towards a stabilized state. Increased dense riparian vegetation and a loss in bare ground from 1987-2007 estimated from satellite data suggests that the impacts of these changes are most severe in the upper reaches of the arroyo toad range. Restoration and management of the habitat are crucial for conservation of this endangered species at Fort Hunter Liggett.

Introduction

The arroyo toad (*Anaxyrus californicus*) is a federally endangered species that inhabits coastal and desert drainages from Fort Hunter Liggett (FHL) in southern Monterey County in California to northwestern Baja California in Mexico (US Fish and Wildlife Service 2001). The species was discovered on FHL in 1996 and determined to occupy 26.7 km of the San Antonio River from approximately 2.4 km northwest of

Mission San Antonio de Padua to the river delta above the San Antonio Reservoir. The San Antonio Reservoir dam was constructed in 1963, which isolated a population of arroyo toads that likely extended to a historic population in the Salinas River (Miller and Miller 1936).

Arroyo toads inhabit dynamic stream systems that experience winter flood events which scour and redistribute sediment, and then diminish surface flow in the spring and summer, often ceasing flow entirely in the fall. Habitat requirements within these systems are age specific to arroyo toads. Adults and juveniles require sandy soils to burrow and open terrain to forage. Egg strands are laid in very shallow water (< 10 cm) with low current velocity and with little to no emergent vegetation. Developing larvae remain in shallow, warm water through metamorphosis. Breeding at FHL typically begins in late April and concludes mid June, and metamorphosis of larvae is generally complete by August (Chapter 2). While presence of water is required throughout this time frame, flow exceeding 2 m³ per second is detrimental to egg strands and developing larvae, thus annual productivity is highly sensitive to late spring storm events or drought conditions.

FHL was established in 1940 to serve as a training site for World War II. Prior to the acquisition of the property, the land had been primarily used for cattle grazing. Training activity during the 1940's and 1950's far exceeded current allowable use. Much of the landscape was burned and extensive erosion, vegetation loss, and off-road vehicle traffic is evident in aerial photographs. FHL continued to lease land for cattle grazing until cessation of the program in 1991. Today military maneuvers are prohibited in the San Antonio River channel. All projects and activities that may negatively impact natural resources require review and clearance from the Environmental Division at FHL (FHL 1996). Upland areas of the San Antonio River are typically used for bivouac or live-fire range activities. Annual burning of the Multi-Purpose Range Complex is conducted

during spring months to reduce incidence of wildfire that may escape into the riparian zone of the river. The FHL arroyo toad population is monitored annually as outlined in the endangered species management plan for the installation (Hancock and Clark 2004).

Despite current protection measures for the arroyo toad population in the San Antonio River, a new threat has developed in recent years: a loss of breeding habitat due to natural succession of the riparian vegetation. Many areas of the river have become incised and occluded by riparian vegetation, often rendering conditions unsuitable for breeding arroyo toads. From the initiation of surveys in 1997 following discovery of the species in 1996, conversion of breeding habitat has been observed and a decrease in occupation of the range by the species is suspected. Breeding surveys since 2005 indicate that arroyo toads are utilizing 61% of their range on FHL, and breeding has not been observed in the uppermost 5 km of their range since 2004 (Chapter 2). Whether these changes are from natural processes (i.e. precipitation patterns, lack of flood events), or from anthropogenic activities (i.e. grazing, control burning), understanding the source of these changes is crucial in devising a plan for restoration and management of the habitat to protect arroyo toads at FHL. To investigate habitat conversion in the San Antonio River and to evaluate the severity of the problem, I used a combination of satellite imagery, aerial photography, precipitation data, river gauge data, and land use history accounts. I extracted areas of greatest concern and identified potential problems to begin the process of restoration planning.

Study Area

FHL encompasses nearly 66,000 ha of the Santa Lucia Mountains in southern Monterey County. The San Antonio River enters the installation near the northwest boundary and empties into the San Antonio Reservoir in the southeast portion of the installation. The 26.7 km section of the river in which arroyo toads occupy transverses

the wide plain of the San Antonio River Valley as a 5th order stream, and comprises intermittent sandy channels and sand bars with low elevation and sandy terraces adjacent to and between braided channels. The width of the floodplain ranges from 80-600 m, yet the width of the active river channel averages 10 m during spring months. The flow of the San Antonio River is seasonal, with surface water present primarily in winter and spring. During the fall, most flow continues underground, however many portions of the river remain perennial. The elevation of the river in the arroyo toad range is 238-317 m. The riparian vegetation canopy is predominately Fremont cottonwood (*Populus fremontii*) or mixed willow (*Salix spp.*) species, and the understory comprises mule fat (*Baccharis salicifolia*), mugwort (*Artemisia douglasiana*), California rose (*Rosa californica*), and California blackberry (*Rubus ursinus*).

I utilized the full extent of the FHL arroyo toad range for analysis in this study (26.7 linear km). This range is almost entirely contained within Training Areas 6B, 16B, 22, 25, and 29; those small portions extending into other training areas were included into analysis with adjacent training areas since land activity in those areas are similar (Figure 3.1). Training Areas are arbitrary land units used for management of FHL training activities. Because activities vary among training areas and may influence habitat differently, I used “training area” as a factor in my analyses. Satellite analyses were constrained to the river corridor and floodplains within the arroyo toad range, however all other analyses extended into upland habitat, which is considered valuable to arroyo toads.

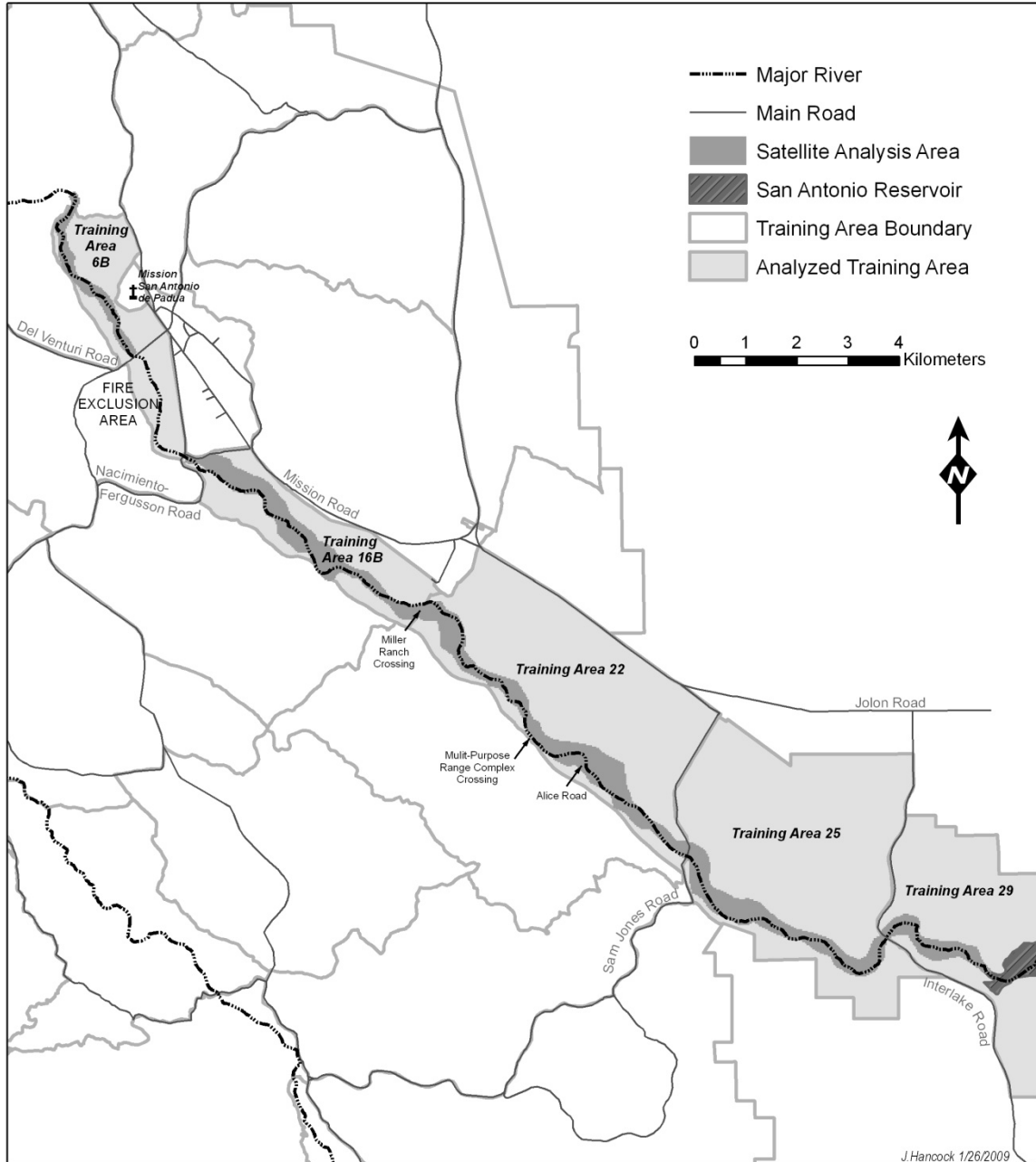


Figure 3.1: Arroyo Toad Habitat in the San Antonio River at Fort Hunter Liggett, with corresponding training areas and satellite analysis area.

Methods

Aerial Imagery Analysis

To determine the relevance of recent changes in arroyo toad habitat, it was important for me to understand the historic conditions of the river through time. To do this, I utilized aerial photographs of the installation. FHL has a collection of georectified aerial photographs of the installation taken by airplane dating as far back as 1929. A set of photographs were obtained about every 10 years, although some portions of the installation were not captured during each flight. For analysis of arroyo toad habitat, I used sets from 1949, 1956, 1963, 1972, 1987, and 1989. I also used 1994 digital orthoquads of the installation and 2002 IKONOS imagery. I created mosaic files using ERDAS Imagine software (Leica Geosystems, Norcross, Georgia) for those years whose pictures were not already combined into a single file. Using ArcMap 9.2 software (ESRI, Redlands, CA), I visually inspected each year and compared features between years and compiled a description of features and changes.

Satellite Data Analysis

To examine habitat change over the past 20 years in the FHL arroyo toad range, I analyzed vegetation reflectance from satellite data. I used Landsat Thematic Mapper 5 data for an area covering southern Monterey County on August 8, 1987, July 2, 1997, and August 15, 2007. Data included six band layers representing the following wavelengths: Band 1, 0.45-0.52 μm ; Band 2, 0.52-0.60 μm ; Band 3, 0.63-0.69 μm ; Band 4, 0.76-0.90 μm ; Band 5, 1.55-1.75 μm ; Band 7, 2.08-2.35 μm . I stacked and subsetted each set of bands for the 26.7 km analysis area, then georectified the data to IKONOS imagery using ERDAS Imagine software. I created an area of interest layer that encompassed the riparian corridor and floodplains of the entire arroyo toad habitat with the exception of an area that was heavily affected by wildfire in the 2007 imagery;

adjacent upland areas were not included to reduce their influence on the pixel values in the analysis area.

I examined vegetation succession in two separate ways: by total bare ground and by dense riparian vegetation coverage. Both tell the same story of succession, but from different perspectives. A loss in bare ground indicates that vegetation succession has initiated in areas that were previously open, whereas a gain in dense riparian vegetation indicates the latter stages of succession which typically coincides with stabilizing of stream banks (personal observation). Open areas are associated with shallow pooling water, which is necessary for arroyo toad breeding, whereas heavily vegetated areas accompany deep pooling water which is unsuitable for arroyo toads.

To isolate the pixels that best represented bare ground, I performed a series of unsupervised classifications with ERDAS Imagine software using variable numbers of classes and compared the results with IKONOS data. I found that a classification scheme with 12 classes best defined the habitat, and that class 12 most accurately represented bare ground. I created a layer file for each year using this scheme and recoded the raster attributes so that class 12 became "1" and all other class became "0." Using ArcMap 9.2 software with a Spatial Analyst extension, I converted the raster files to shapefiles and exported the analysis area as a single file.

To isolated pixels that best represented dense riparian vegetation, I first applied a transformed normalized vegetation index to each year's data set. The calculation for this transformation is the difference of near-infrared and visible reflectance values divided by the total reflectance, which result in enhanced differentiation of vegetation versus bare ground based on increased cover and/or vigor of the vegetation (Leo et al., 2000). I repeated the same steps as described for isolating bare ground, although for this analysis, I found that a classification scheme with 8 classes was appropriate and class eight best represented dense riparian vegetation.

Once I obtained files for bare ground and dense riparian vegetation, I ran a number of analyses to see how each changed over the past 20 years. To begin, I calculated pixels into ha (pixel size is 28.5 x 28.5 m), and looked at the percentage of bare ground and dense riparian vegetation per training area per year. I entered these data into Minitab (Minitab Inc., State College, Pennsylvania) and conducted a multiple analysis of variance test to determine a difference in the percent bare ground or dense riparian vegetation per year and per training area. I used Tukey's method of comparison with 95% confidence intervals to identify differing values when the p-value of the test was below a 0.05 significance level.

Next I looked at transitioning habitat, in particular where areas have experienced a loss of bare ground followed by a gain in dense riparian vegetation over the course of 20 years. To assess these changes, I used ArcMap 9.2 to overlay the 1987 bare ground/dense riparian vegetation files with the 2007 files and used clip and erase functions to create three new files: gain, (portions present in 2007 and absent in 1987), loss (portions present in 1987 and absent in 2007), and unchanged (portions present in both 1987 and 2007). I calculated the percent gain and loss for both habitat states per training area and performed a paired t-test with Minitab to test the hypothesis that there is no difference between gained and lost areas using a significance level of 0.05.

To evaluate where these changes have been occurring and how it has affected the arroyo toad breeding population, I identified areas in the landscape that have had a considerable gain in dense riparian vegetation and/or loss in bare ground; areas that were largely unchanged or had a relatively equal loss and gain were considered marginal habitat changes. The most extreme change would be a conversion from bare ground in 1987 to dense riparian vegetation in 2007. If this were to occur in the vicinity of a reduction in arroyo toad breeding activity, then I would consider the change to be adversely affecting the species. Areas where a loss in bare ground occurred in close

proximity to a gain in dense riparian vegetation and a reduction in arroyo toad breeding activity would indicate that a process is underway that is potentially disadvantageous to the species. I identified these areas of concern as candidate restoration sites. To identify such areas, I used the select by location tool in ArcMap to highlight I overlaid the files with 2002 IKONOS imagery in ArcMap to identify areas that experienced a great gain in dense riparian vegetation and loss in bare ground, where the two occur within 100 m of each other, and where they intersect. Areas that were barren in 1987 and exhibited dense riparian vegetation 20 years later suggests accelerated vegetation growth, and are potential areas of concern. Finally I compared these areas with arroyo toad oviposition sites occurring in 1998-2008. I identified areas that displayed a considerable gain in dense riparian vegetation, loss of bare ground, and absence or reduction of oviposition sites as areas of concern and candidate for restoration.

Environmental and Anthropogenic Influences

Prior to designing a restoration, an understanding of the environmental and anthropogenic influences affecting vegetation succession in arroyo toad habitat is crucial. For example, changes in precipitation and or flood events may, over decades, prevent scouring and create alteration in sediment deposition which may require aggressive stream bank alteration treatments, whereas a river crossing, affecting only adjacent habitat may be improved by minor changes. With this in mind, I explored potential environmental and anthropogenic influences affecting observed changes in the FHL arroyo toad habitat.

The environmental variables I examined were precipitation, river discharge, and active channel location. I evaluated precipitation totals and patterns, and river gauge data to determine whether or not sufficient scouring events have been occurring. I used precipitation data from the San Antonio Valley Test and Experimental Command

Meteorological Station and the Western Regional Climate Center to look at monthly and annual totals and precipitation patterns. I compared annual totals from 1987-1997 with totals from 1997-2007 by sorting the values from lowest to highest and performing a paired t-test to see if there were significant differences in rainfall between the two time periods (significance level = 0.05). I repeated the same method with annual maximum discharge collected by the US Geological Survey at Interlake Road (Station 11149900). Using aerial imagery of the installation in 1987, 1989, 1994, and 2002, and field data collected in 2007, I created GIS files of the San Antonio River course and identified portions of the river that have shifted laterally. I overlaid these files with the increased dense riparian vegetation file and the decreased bare ground file to evaluate the influence of course change on habitat change.

Finally, I investigated anthropogenic activities to determine their affect on habitat changes. I examined historical documentation of cattle grazing and cultivation, and compared records with the satellite data analysis and aerial photographs to investigate the affect of anthropogenic activities on arroyo toad habitat. I evaluated the effect of wildfire on vegetation structure in Training Area 22, where escape from annual control burns is common. I assessed the impacts of the three hardened water crossings within arroyo toad habitat on the streambed structure through time with aerial imagery (1949, 1956, 1963, 1972, 1987, 1994, and 2002) and determined the extent to which they have influenced vegetation changes.

Results

Aerial Imagery Analysis

The San Antonio River in 1949 was braided and had extensive sandy washes. Most of the corridor was scattered with large trees and frequently paneled with well developed woodlands. The 100 year old floodplain was moderately vegetated with scrub and chaparral, and the upper terraces were frequently cultivated. By 1956, a significant loss of vegetation was apparent over the range. The most extensive vegetation loss occurred in Training Area 22, which lost approximately 90% of its large trees by 1963 (Figure 3.2 a-b). Adjacent uplands were heavily burned, which indicates that fire was likely the source of vegetation loss. Vehicle tracks were abundant and were not confined to a road system. Recovery of scrub vegetation was observable in 1987, yet tree loss continued in Training Area 22 (at a reduced rate). Lateral shift of the active river channel was minor throughout the range until 2002, with the exception of Training Area 22 where severe vegetation loss increased mobility of the channel. In 1994, portions of the river began to exhibit large-scale pooling with increased bank vegetation. American beaver (*Castor canadensis*) activity, which was previously undetected, was also apparent in 1994. One beaver dam observable in Training Area 22 still exists today (although the exact location has shifted laterally with the river course (Figure 3.2 c-d). In 2002, bank vegetation had increased in these stabilized areas, and many areas with extreme lateral shift resulted in erosion of upland terraces. Overall, habitat changes were most extreme in Training Area 22, whereas Training Areas 25 and 29 changed very little. Training Areas 16B and 6B experienced moderate changes, becoming more pronounced from 1994 to 2002.

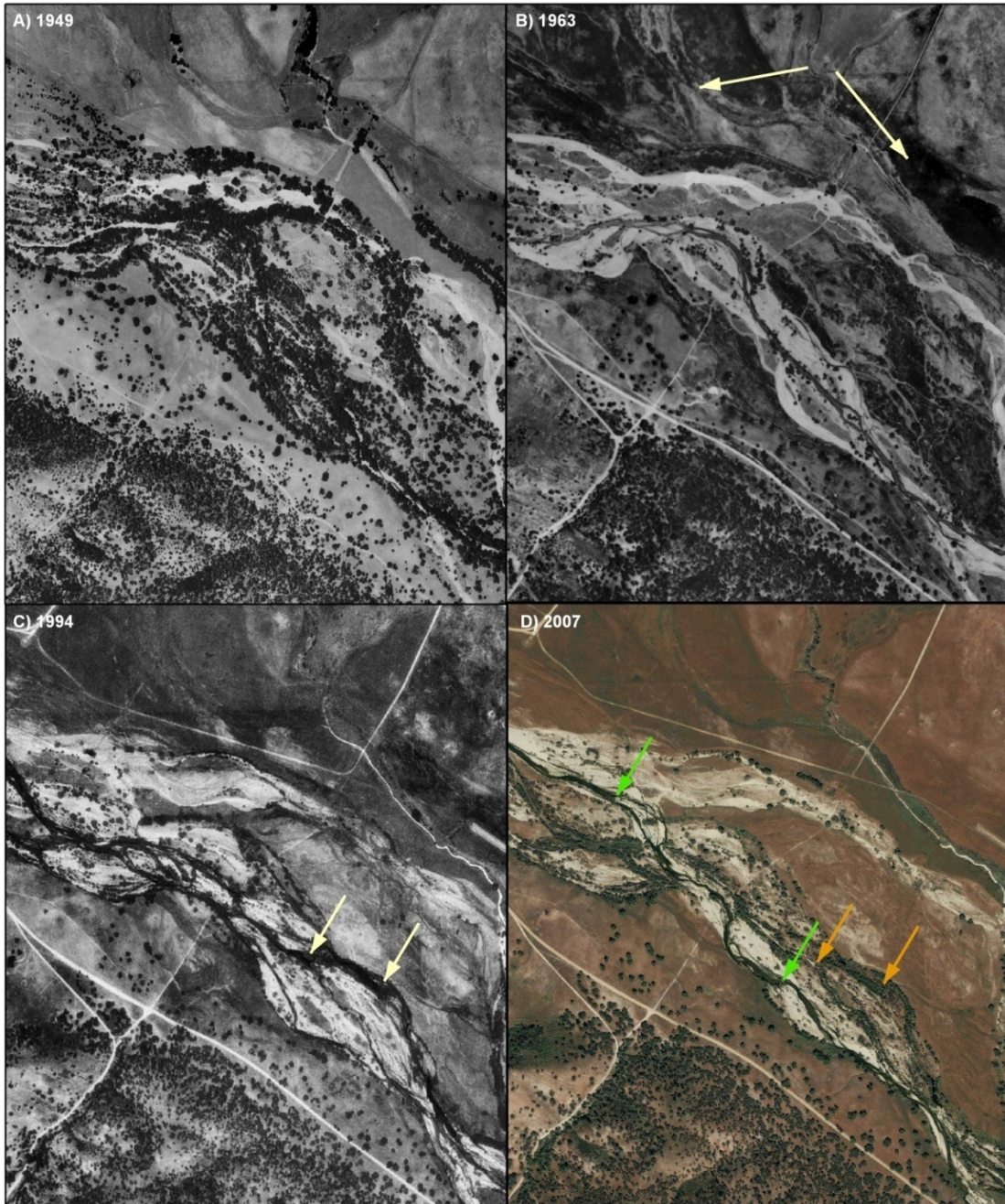


Figure 3.2: Training Area 22 in the vicinity of Alice Road in A) 1949 exhibiting expansive riparian woodlands, B) 1963 with extensive tree loss and burned upland terraces (arrows), C) 1994 with two beaver dams (arrows) and slight vegetation recovery along stream banks, and D) in 2002 with two newly established beaver dams (green arrows) and former 1994 beaver dams (orange arrows) and increasing bank vegetation.

Satellite Data Analysis

The satellite analysis area was approximately 834 ha and measured 25.1 linear km. The total bare ground detected by satellite analysis varied per year and per training area (Figure 3.3). While the total area of bare ground was greatest in 1987, there was no statistical difference in the total area per year ($P = 0.292$). Bare ground was significantly different among the training areas ($P = 0.000$); Training Area 6B had overall less bare ground coverage than Training Areas 16B, 22, and 25.

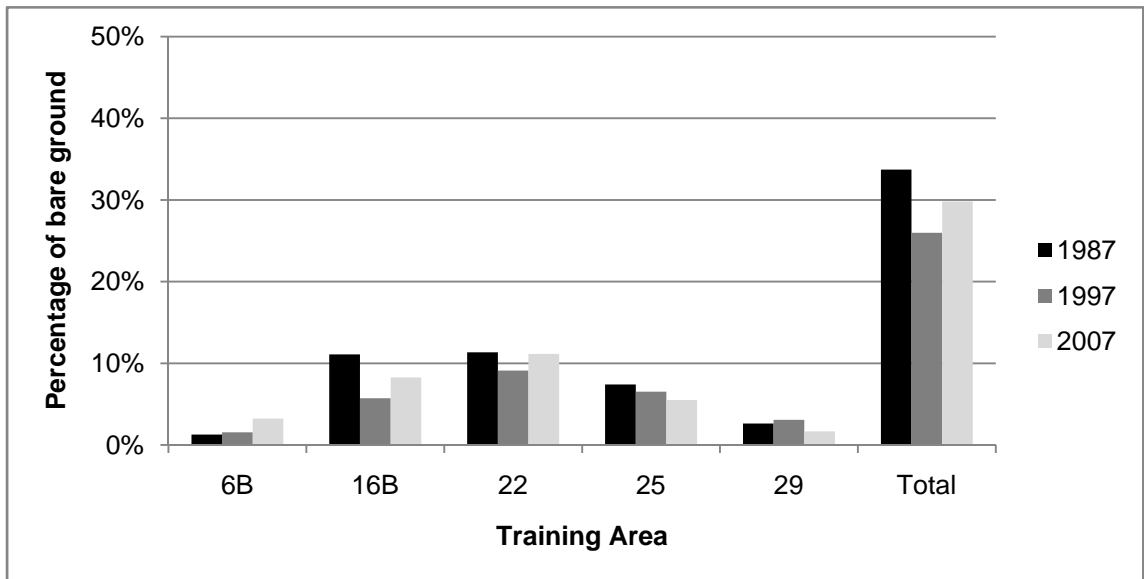


Figure 3.3: Percentage of bare ground in arroyo toad habitat at Fort Hunter Liggett in 1987, 1997 and 2007.

Dense riparian vegetation composed 12% of the analysis area in 1987, 13% in 1997, and 15% in 2007. While these values increased per decade, results varied per training area: there was a gain in dense riparian vegetation in Training Areas 6B, 16B, and 22, and a loss in Training Areas 25 and 29 (Figure 3.4). Despite the gradual increase in the total area of dense riparian vegetation over the two decades, there was no statistically significant difference in the totals for the three years ($P = 0.927$). The total

area of dense riparian vegetation was significantly greater in Training Areas 25 and 29 than in the other three training areas ($P = 0.008$).

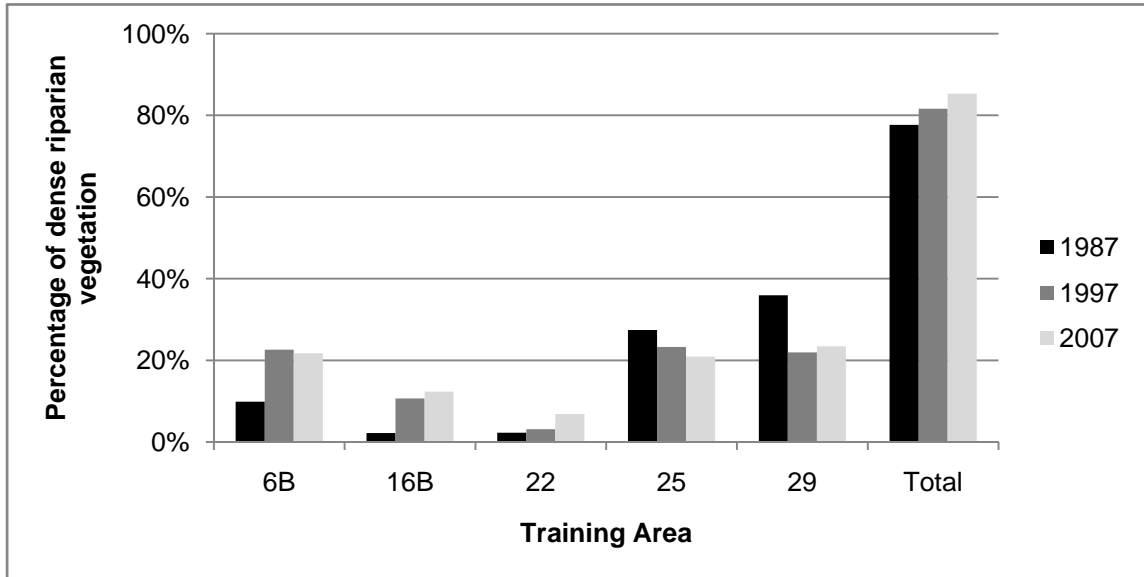


Figure 3.4: Percentage of dense riparian vegetation in arroyo toad habitat at Fort Hunter Liggett in 1987, 1997, and 2007.

The loss in bare ground coverage exceeded the gain from 1987-2007, however the difference in the two was not significant ($P = 0.766$). Gained and lost bare ground was variable among the training areas (Figure 3.5).

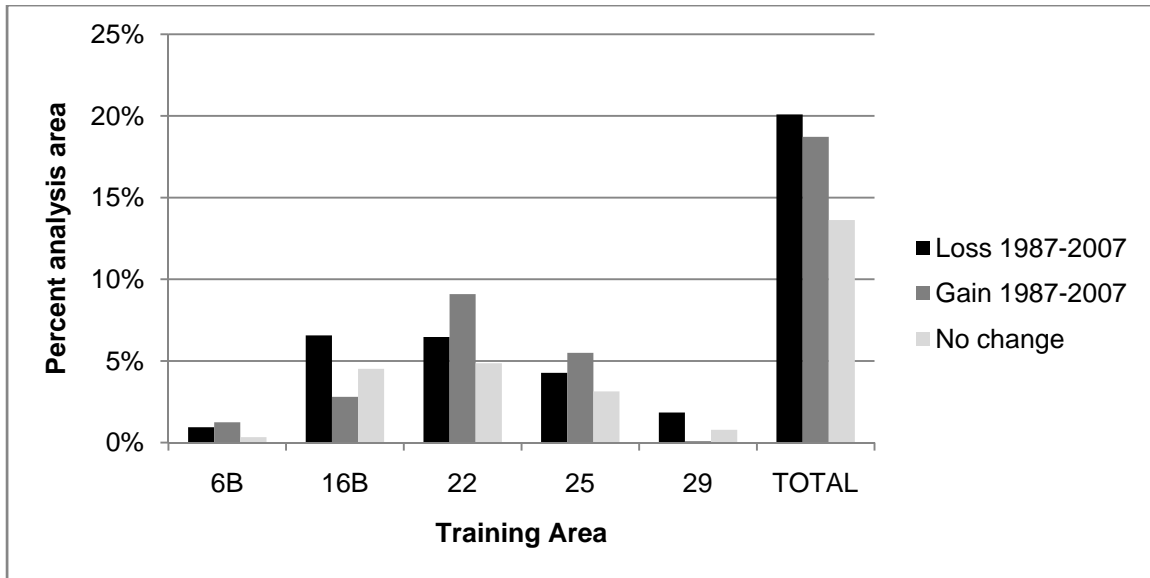


Figure 3.5: Percentage of decreased, increased, and unchanged bare ground coverage in arroyo toad habitat at Fort Hunter Liggett from 1987-2007.

The gain in dense riparian vegetation was greater than the loss from 1987-2007, however the difference was not significant ($P = 0.907$). The overall measurements however did not reflect the changes among the training areas. There was a considerable gain in dense riparian vegetation in Training Areas 6B, 16B, and 22, which was balanced by a loss in Training Areas 25 and 29 (Figure 3.6).

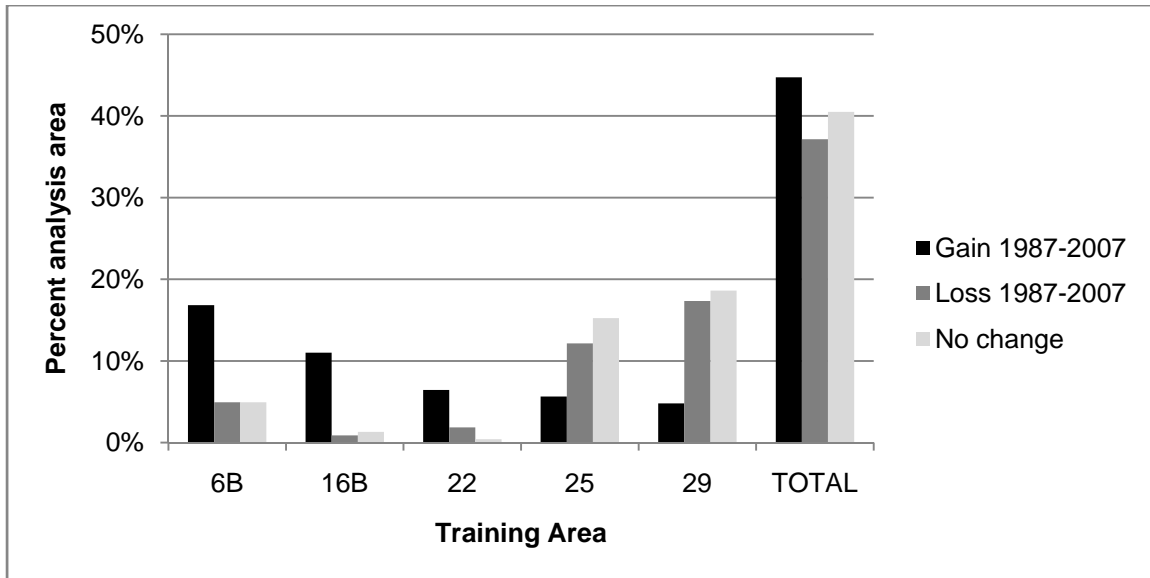


Figure 3.6: Percentage of increased, decreased, and unchanged dense riparian vegetation coverage in arroyo toad habitat at Fort Hunter Liggett from 1987-2007.

The most expansive areas of gained dense riparian vegetation occurred in the upper 4 linear km of Training Area 6B and the upper 2 linear km of Training Area 16B. The area where gained dense riparian vegetation and lost bare ground occurred within 100 m of each other was greatest in Training Area 16B, and included approximately 10% of the entire analysis area (Figure 3.7). The total area in which bare ground loss directly overlapped with gained dense riparian vegetation was 3.7 ha. Many of these overlap areas occurred within 50 m of an arroyo toad oviposition site. A reduction of oviposition activity from 2004-2008 occurred in proximity to 20% of the overlap areas, all, with the exception of one site, within Training Area 16B.

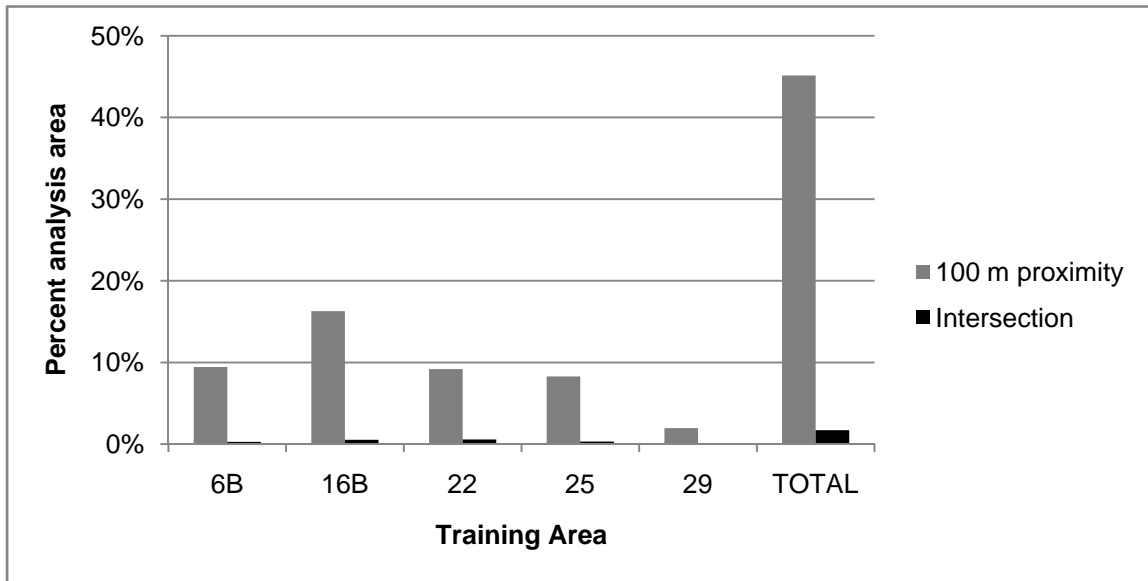


Figure 3.7: Percentage of increased dense riparian vegetation within 100 meters of decreased bare ground and percentage of area where increased dense riparian vegetation overlaps with decreased bare ground in arroyo toad habitat at Fort Hunter Liggett from 1987-2007.

Environmental and Anthropogenic Influences

Lateral shift of the active river channel occurred in all training areas from 1987 through 2007. Small linear sections (< 300 m) were common, and typically shifted less than 50 m laterally. A 1200 linear m section in Training Area 16B shifted 260 m laterally from 1994 to 2007, but was not associated with the significant increase in dense vegetation seen elsewhere in the training area. An association between linear shift and increased dense riparian vegetation is suspected in Training Area 22. Riparian vegetation in the 2002 Ikonos imagery is most prominent in the 1994 active channel, however vigor is greater where water currently flows (Figure 3.8). The upland terraces of this training area are burned annually, and commonly include wildfire from escaping

flames. For this reason, vegetation is reduced in areas with no water (former active channels). There is no indication that lateral shift affects dense vegetation growth unless accompanied by regular wildfire.

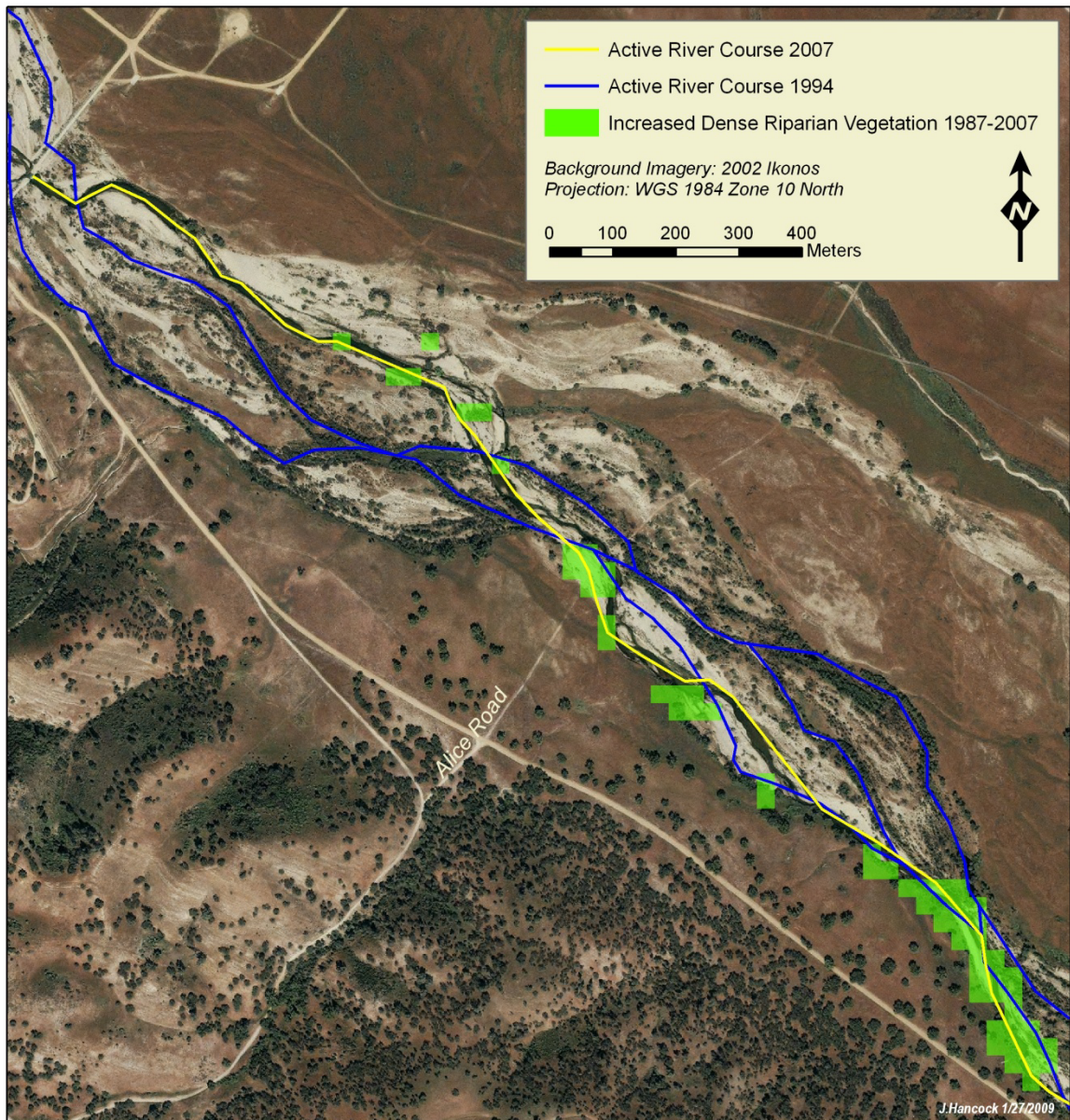


Figure 3.8. San Antonio River course in 2007 and 1994 with increased dense riparian vegetation from 1987-2007 in Training Area 22 at Fort Hunter Liggett.

FHL annual precipitation totals (July-June) were similar from 1987-1997 to 1997-2007 despite high variability (Table 3.1). A paired t-test of sorted annual totals found no significant differences between the two ranges of years ($P = 0.216$). Months with precipitation greater than 25 cm were more common 1987 through 1997 (5 months compared to 2 from 1997 through 2007), and may have produced a greater number of productive scouring events that could have affected vegetation growth in 1997.

Table 3.1: Summary of Fort Hunter Liggett San Antonio Valley annual (July-June) precipitation (cm) for 1987-1997 and for 1997-2007.

Range of Years	Number of Rain Years	Total Precipitation	Annual Average	Annual Maximum	Annual Minimum
1987-1997	11	519.84	47.26	91.90	26.30
1997-2007	11	561.26	51.02	119.05	18.54

From field observations, discharge in the San Antonio River exceeding 56 m³ per second (cms) was deemed significant; this flow was sufficient to dismantle substantial beaver dams. Annual peak flow for the San Antonio between 1987 and 2007 exceeded 56 cms in 15 of 21 years. Annual peak flow exceeded 141 cms in five years between 1987 and 1997, and in five years between 1997 and 2007. The sorted annual maximum discharge for 1987-1997 was not significantly different than those for 1997-2007 ($P = 0.287$).

Cattle grazing had been practiced on FHL lands since the establishment of Mission San Antonio de Padua in 1771. After military acquisition of the property in 1940, the installation leased grazing rights from 1942 until 1991. Grazing occurred year round, and although a 1971 study indicated forage was good, it was determined that FHL was considerably overstocked and the land could not support continued grazing practices as

established (Biswell 1971). Several range studies were conducted in the years following. Major damage to habitat was noted between 1972 and 1977 (Leopold 1979) and woody vegetation along stream courses was virtually eliminated (McCullough 1983). Several recommendations were made to the FHL Command to aid restoration of the habitat: fencing to exclude cattle from riparian habitat (Menke 1976), reduction in the number of cattle stocked (Menke 1979), and implementation of seasonal grazing from November through June (Leopold 1979, Menke 1981). Finally in 1982, seasonal grazing was implemented and increased canopy growth in the riparian corridors was immediately observed (Menke 1983, 1985, McCullough 1983). In 1991, a study was conducted to evaluate existing range conditions and it was determined that despite recovery of riparian habitat, overall residual forage was low and bare ground was extensive (24.7% opposed to 6.8% in 1977). Because of the potential for severe negative impacts to the natural resources, including riparian habitat, it was recommended that FHL should not permit grazing practices until recovery of the land was achieved (Littlefield 1991). As a result, grazing practices were temporarily halted for further study. In 1992, a draft environmental assessment for livestock grazing was prepared, which determined that mitigated grazing practices would have no significant impact (Jones & Stokes 1992), however due to conflict with military activities and sensitive resource protection issues, the document was not finalized and the installation has not reinitiated the program.

Dry farming and irrigated cultivation occurred in the upland terraces of the San Antonio River during the Mission Era and was continued by American settlers. Although cattle grazing was the primary agricultural practice in the area, cultivation was common in the upland terraces of the San Antonio River. While dry farming was the most common practiced cultivation, there was evidence of irrigated land in the uplands north of the San Antonio River in Training Area 16B into the early 1960's. This cultivation is relatively small (< 10 ha) and likely had no effect on the river hydrology. However, in the

1960's and 1970's, adjacent lands east of FHL sharing the same groundwater basin were extensively irrigated, which substantially lowered the groundwater table (Nacitone Watersheds Steering Committee and Central Coast Salmon Enhancement, Inc. 2008). Water elevation began to recover in the 1980's and leveled in 1998; the groundwater elevation rose approximately 14 m from 1987-1997. This increase in groundwater elevation may have increased surface water, positively affecting vegetation growth from 1997 through 2007.

Fire has been utilized by the Army since acquisition of the land, and remains an important land management tool for FHL today. Due to low precipitation, high summer heat, and low humidity, wildfire as a result of military activity is inevitable. To prevent such incidences which disrupt training exercises, control burns are conducted during the late spring to reduce fuel load. Annual burns are conducted on the live-fire ranges in Training Area 22. Although the San Antonio River corridor is not intentionally burned, fire often escapes into the riparian zone. As a result, the vegetation in this training area is maintained primarily within a mid-successional growth state. From 1998-2007, an average 27% of the analysis area in Training Area 22 was affected by wildfire each year. Already determined with the evaluation of lateral shift of the active channel, dense vegetation occurs only where water is present (Figure 3.8). While fire is beneficial in reducing the negative impacts of increased dense vegetation growth, it also promotes erosion and colonization of invasive plant species, such as salt cedar (*Tamarix parviflora*) and yellow star-thistle (*Centaurea solstitialis*) which are widespread in Training Area 22.

There are three concrete water crossings in the arroyo toad range on FHL: Del Venturi Road in Training Area 6B, Nacimiento-Fergusson Road in Training Area 16B, and the center lane of the Multi-Purpose Range Complex (MPRC) in Training Area 22. Each crossing affects upstream and downstream streambed and vegetation structure,

but in varying ways. The Del Venturi crossing has high sediment load encouraging vegetation growth in the channel up- and downstream. From 1987-2007, the upstream vegetation has encroached on the eastern bank constricting water flow to half the original channel width. Downstream, vegetation completely occludes the channel for approximately 60 m. This site was formerly quarried for cobble and was cleared annually until 1997 when arroyo toads were discovered occupying the area. Although this section was not analyzed on the satellite data due to the 2007 burn, increased vegetation growth is apparent on aerial imagery from 1994 to 2002. In February of 2004, the vegetation downstream of the crossing was removed in order to preserve the structural integrity of the crossing during high winter flows; four years later no evidence of such activity is discernable (Figure 3.9). Further downstream the channel is deep and the banks are entrenched. In 2003, an arroyo toad oviposition site was detected 280 m downstream of the crossing. Oviposition has not been observed in this location since; the next proximal site was detected in 2008, 620 m downstream of the crossing.



Figure 3.9: Concrete crossing on Del Venturi Road, Fort Hunter Liggett in A) 2004 following removal of stream vegetation, and in B) 2008 with stream channel occluded by vegetation.

Sedimentation and vegetation encroachment on the upstream southwestern bank of the Nacimiento-Fergusson concrete crossing has resulted in a reduction of the channel to nearly half its original width. This vegetated bank is entrenched and the channel is relatively deep. A plunge-pool exists downstream of the crossing and water flow is constricted to the extreme southwest edge of the channel. With the exception of flood events, the channel has not moved from this course since its construction over 45 years ago. Calculated from the satellite data, the next 650 linear m downstream of this crossing contain the most extensive increase in dense vegetation. Although there are few isolated locations suitable for arroyo toad oviposition within this segment, most of the habitat is unsuitable for breeding due to dense vegetation and deep pooling water.

The MPRC crossing was built in the mid 1980's. This crossing is in a relatively wide location of the San Antonio River spanning 180 m. The channel is flat, sandy, and braided and is sparsely vegetated. Water flow was unrestricted by the crossing until a repair was made in 1997 after winter floods dismantled a 30 m section of the crossing. The repaired design left this section intentionally lower than the rest of the crossing drastically constricting water flow and severely affecting streambed conditions up- and downstream. Vegetation is swiftly encroaching into the upstream channel, and extensive entrenchment and erosion continues downstream (Figure 3.10). The stream regains its meandering pattern 800 m downstream. Arroyo toads continue to breed up to this point, however the number of oviposition sites increase by 50% beyond 800 m downstream.



Figure 3.10: Concrete crossing on the Multi-Purpose Range Complex, Fort Hunter Liggett in A) 2003 with minimal vegetation growth and in B) 2008 with excessive vegetation growth.

Discussion

The general findings of the analyses support my interpretation of the changes that I have observed in the system within recent years. Not only has there been a considerable gain in dense riparian vegetation, the gain is most prominent in Training Areas 6B, 16B, and 22. In most areas, a gain in dense riparian vegetation results in decreased arroyo toad breeding activity (Training Areas 6B and 16B). The anomaly occurs in Training Area 22; the frequency of oviposition is greatest in this area, yet this area also contains the most extreme erosion, the most infallible beaver dams, and the highest occurrence of deep, perennial pools surrounded by thick vegetation. The difference may be that of the stream course, this area has the greatest potential for lateral shift. The floodplain is at its widest through much of Training Area 22, accommodating overbank flooding at established beaver dams and or other occluded sites. Frequent fire reduces the stabilizing affects of bank vegetation and keeps secondary channels relatively free of dense vegetation, thereby providing auxiliary breeding habitat in years of above average rainfall. While this area suffers from the same issues as upstream, priority for restoration at this location may be secondary.

The need for restoration is greatest in Training Area 16B where vegetation succession is rapidly advancing and the quality of arroyo toad oviposition sites are deteriorating. This area has the highest occurrence of increased dense riparian vegetation in proximity and in overlap with loss of bare ground. However, unlike the upper reaches of Training Area 6B which may have been abandoned by arroyo toads, and unlike Training Area 22 where the species remains prevalent, activity in this region is waning. This combination of rapid succession and reduction in breeding activity warrant the need for restoration to slow, halt, or reverse habitat degradation. Three locations in this training area are candidate for restoration: downstream of the Nacimiento-Fergusson crossing, west of the landfill, and from Oro Fino Canyon to Schoonover Airfield (Figure 3.11).

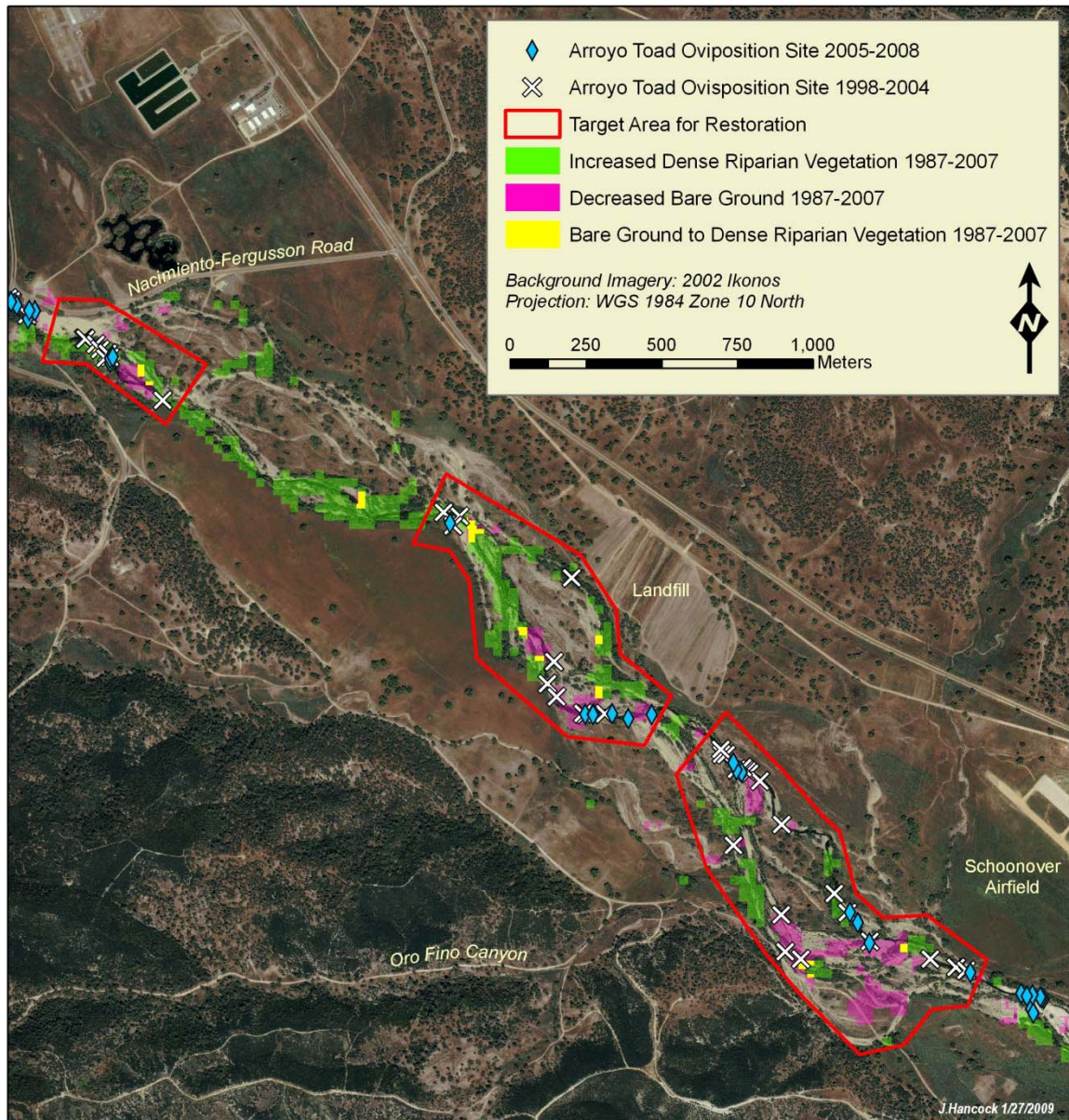


Figure 3.11: Three target areas for habitat restoration of arroyo toad habitat at Fort Hunter Liggett based upon presence of increased dense riparian vegetation and decreased bare ground from 1987-2007, coupled with reduced breeding activity from 2005-2008.

The most striking discovery during my research was that the San Antonio River was once much more vegetated than it is currently. The 1949 aerial imagery shows

extensive riparian woodlands throughout the entire FHL arroyo toad range; today's open washes and floodplains were once rich with expansive scrub vegetation. Intuition would guide that recovery of vegetation in the system would bring it back to its previous state. However we know that something deleterious is occurring by evidence of a retracting breeding range. It may be in the type of vegetation recovery that we are witnessing and where it is occurring. In 1949, the channels were wide and flat, allowing the stream to meander from bank to bank. Today that sinuosity has decreased and vegetation is more prominent in the active channel itself. Occlusion of the channel and stabilization of the banks have consumed shallow pooling areas that may have once been abundant.

While gained dense riparian growth and loss of bare ground in the past 20 years can be associated with degradation of habitat, the origin of this change likely extended much farther back in time. It is unquestionable that the most momentous alteration occurred when the San Antonio River Valley lost extensive riparian woodland and scrub habitat between 1949 and 1963, destabilizing the river system. It was during this time arroyo toad habitat was imperiled. As cattle grazed, and groundwater was being compromised by farming in the valley, the river appeared stable under the artificial conditions, masking the affects of the changed hydrology and sedimentation patterns. Presently, with no riparian vegetation growth control, natural succession is occurring and the channel is stabilizing. Fire, likely the cause of the devastating vegetation loss, is now responsible for maintaining suitable arroyo toad habitat, as is evident in Training Area 22. Precipitation and river discharge typical for this region may not be sufficient to counteract the channelization, incision, and erosion so prevalent through the affected areas.

There was no indication that precipitation or river flow was unusual during the past 20 years, so the rate of vegetation growth should be stable for the area. Cessation of cattle grazing and groundwater recovery from intensive farming in the valley likely had

the greatest widespread impact on vegetation growth, and could potentially account for accelerated vegetation growth in localized areas. Hardened water crossings have negatively impacted adjacent habitat, but are not suspect of widespread channel stabilization, incision, and erosion. Fire, which is culprit to such channel features, also tends to counteract deleterious effects of vegetation growth. It is conceivable that degradation of the habitat has ensued due to a combination of factors, both environmental and anthropogenic. Likely, typical storm events at FHL are not sufficient to scour the system without the added grazing pressure which reduces the stabilizing effects of the riparian vegetation. Perhaps the San Antonio River is stabilizing to a natural course defined by the geomorphology of the system.

Management Implications

Deleterious effects of a reduction in range or loss of suitable breeding habitat are compounded at FHL with isolation and range restriction from natural barriers. A constricted population is susceptible to outbreaks of lethal pathogens and extinction potential is greater with a catastrophic event such as a severe drought spanning multiple years. Without immigration from satellite populations, recovery from such an event is unlikely. As a result, any habitat loss should be regarded with great concern. Arroyo toad habitat at FHL, which was compromised by the construction of the San Antonio Reservoir, has experienced localized areas of degradation, fragmentation, and constriction. In addition, channel stabilization and incision promote deep pooling water, which in turn provide essential habitat for bullfrog reproduction and survival. Since bullfrogs occupy all reservoirs and most stream systems on FHL, means of exclusion of the species from the San Antonio River is impractical. The most feasible method of bullfrog control is through habitat restoration.

To design an appropriate streambed restoration and maintenance plan, FHL would need to consider geomorphologic conditions of the San Antonio River (Rosgen 1997). Restoration should begin at selected areas in which an alteration may be an immediate benefit to arroyo toads, specifically those areas outlined in Training Area 16B (Figure 3.11). Additional restoration would be beneficial in the vicinity of the three hardened water crossings or where stream stabilization and incision has led to extreme erosion. An approach to restoration and applied treatments should consider arroyo toad habits and utilization of riparian vegetation. Vegetation removal on sandy banks or floodplains is not advisable, for these are areas in which adults may be burrowed. Rather passive treatments such as brush revetments at erosion sites to slow water velocity or wattle siltation fences to redirect flow and promote sediment deposition. Another treatment that may be beneficial is the removal of beaver dams prior to winter floods to assist scouring effects of the high water flow.

During the past two centuries cattle grazing may have been an unintended means of maintaining arroyo toad habitat suitability by suppressing vegetative growth and allowing lateral shift, winter scouring, and alluvial deposits. While proper utilization of cattle grazing as a means to maintain mid-successional riparian vegetation may be potentially beneficial, re-establishment of a grazing program at FHL is a low priority due to complexity of needed management coupled with increased military activities. If it were to be reinstated, it is likely that leased lands would be significantly smaller than previous, and sensitive areas, such as riparian corridors, would be excluded from grazing areas. In the absence of such vegetation manipulation, the San Antonio River can be expected to become more incised, the riparian vegetation more dense, and overall more suited for exotic species, such as bullfrogs and beavers. For the benefit of arroyo toads, it is imperative that FHL proceed with a restoration plan that will support the continued effort to protect and provide for the endangered species.

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CHAPTER 4: Habitat Restoration for Arroyo Toad Conservation at Fort Hunter Liggett, California

Introduction

The arroyo toad (*Anaxyrus californicus*) population at Fort Hunter Liggett (FHL) is a US Fish and Wildlife Service recovery unit for the federally endangered species (US Fish and Wildlife Service 1999). This is one of 19 populations that must remain self-sustaining in order for federal delisting of the species. Conservation and protection measures for arroyo toads are described in an Endangered Species Management Plan for FHL. This management plan describes activity restrictions in critical habitat for arroyo toads, but does not describe habitat restoration strategies. The purpose of this chapter is to outline basic steps to begin planning for restoration of the arroyo toad breeding habitat at FHL.

Arroyo toad habitat has been protected at FHL since discovery of the species in 1996. The toad population at FHL occupies 26.7 km of the San Antonio River upstream of the San Antonio Reservoir in Monterey County. The population range is defined by a steep rocky canyon upstream and the reservoir downstream, which may prevent movement of the species in or out of this defined range. No other arroyo toad habitat occurs on the installation. The habitat is protected from all installation activities except recreation, which is limited to game hunting. Access to the San Antonio River is by foot only except at designated crossing areas. Cattle grazing, which was a prominent land practice until cessation of the program in 1991, is no longer permitted on installation land.

Despite few obvious anthropogenic threats, my research has demonstrated a contraction in the distribution of arroyo toad oviposition sites over the past four years coincident with a loss of suitable breeding habitat (Chapter 2). Within the past 20 years,

the braided system of the San Antonio River has become moderately entrenched with reduced sinuosity. The loss of open, sandy reaches has been unfavorable for the arroyo toad, which requires shallow pooling water for oviposition. Vegetation succession and bank stabilization has increased the formation of deep pools that support predatory bullfrogs (*Lithobates catesbeianus*). Arroyo toads have not been detected in the northernmost 5 km of the range since 2004 where habitat changes have been most prominent (Chapter 2). Because arroyo toads may only breed a maximum of four years (Sullivan and Sweet 2005), it is likely that the species no longer occupies those 5 km of habitat, reducing the occupied range from 26.7 km to approximately 21.7 km (Chapter 2). Continued fragmentation and loss of breeding habitat could potentially lead to a decline in the population (Fahrig 1998).

To halt or reverse the observed declining trends in arroyo toad oviposition and breeding habitat availability, I recommend that the installation improve breeding habitat conditions in the San Antonio River through carefully planned habitat restoration, monitoring, and adaptive management. Desirable stream restoration would allow for natural flow and sediment movement processes of the San Antonio River to maintain a braided system. Not only would this increase available breeding habitat for arroyo toads, but it would subsequently reduce deep, shaded pooling areas that support bullfrogs. While a detailed restoration plan is out of scope for this thesis, I outline basic steps to begin planning for restoration of the arroyo toad breeding habitat at FHL: (1) Develop a restoration strategy using principles of adaptive management, (2) Monitor stream geomorphy, riparian vegetation, and arroyo toad oviposition before and after restoration activities, (3) Document restoration effectiveness and adapt future or ongoing activities to maximize restoration success based on pre-defined goals.

Develop a restoration strategy

An effective restoration plan must begin with a clear objective (Kondolf 1995): improve arroyo toad breeding habitat in the San Antonio River. Restoration activity planning will also need to identify what the problem is, where the problem occurs, what is likely causing that problem, where restoration would be most effective, and what time or funding limitations might influence restoration design and implementation. The remote sensing analysis of changes in arroyo toad breeding habitat described in this thesis (Chapter 3) can be used as a starting point to identify potential problem areas, but a more detailed field-based assessment of potential and existing suitable habitat may be necessary. Potential rehabilitation sites may be used to increase continuity along the river or to restore an area that has recently been degraded where the species is still likely present. Due to the stochastic geomorphology of rivers, restoration design and implementation may be unique to each selected site and consider the influence of future flow patterns, spates, and sediment loads. The dynamic nature of this system requires a flexible, adaptive approach to restoration. Initially, each restoration project could be considered an experiment (Kondolf 1995) with ongoing evaluation of success and adaptability of strategies to continually achieve the defined restoration goals.

Funding will likely be the most limiting factor of implementation of restoration projects, and thus must also be taken into account at every step of the planning process. An elaborate restoration project may not be worthwhile if post-project monitoring cannot be conducted. It may be prudent to begin with small-scale projects, for example dismantling abandoned beaver (*Castor canadensis*) dams in the fall or removing vegetation surrounding concrete crossings. Most beaver dams are destroyed during winter floods, however few persist and are rebuilt annually. These dams have stabilized the upstream channel and have promoted successional vegetation growth into the channel (Chapter 3; Figure 3.2). While the unfavorable up- and downstream effects of

the three concrete water crossings in the arroyo toad range may not be nullified without removal of the necessary crossings, reducing the vegetation surrounding the structures will reduce upstream sedimentation and increase water velocity during flooding events and promote vegetation scouring downstream (Chapter 3). Beaver dams may be dismantled by hand crews and vegetation surrounding crossing may be cleared using an excavator with a claw attachment perched from the crossing. Both projects may be conducted by installation personnel.

Monitor and evaluate restoration effectiveness

I recommend quantitative monitoring of the environmental and population response to restoration treatments (Kondolf and Micheli 1995; Roni et al. 2002; Shields et al. 2003). Project monitoring prior to and after restoration treatments are imperative to gauge project success (Kondolf and Micheli 1995). There are two general data sets needed: stream condition and response, and species condition and response. Baseline data collected prior to restoration treatments will set parameters for which the measure of success can be determined during post evaluation (Kondolf 1995). These parameters need to be identified as soon as possible and incorporated into annual monitoring of the arroyo toad population and its habitat at FHL. Current annual data collection should be evaluated and modified to suit information needs in relation to habitat management objectives. For example, FHL should consider annual oviposition site census for the entire 26.7 km range. Not only would this provide an estimation of breeding population size, but it also provides a direct species response to habitat condition. In addition, FHL may also want to consider including an inventory of aquatic macroinvertebrates, which could be used as an indicator of stream water quality (Kondolf and Micheli 1995).

Habitat and stream monitoring needs to be repeatable, defensible, and temporally and spatially scaled to the restoration activity. Cross-section transects are

ideal to measure geomorphic and vegetation structure of the channel. Transects should extend to width of bankfull flow and should be placed appropriately to capture predicted stream response to restoration treatments (Kondolf and Micheli 1995). The number and placement of transects will depend upon size of the restoration project and surveyor effort. Post- monitoring of the environmental response to determine effect of restoration treatments will likely require multiple years of data collection. Due to the variability in the strength of flood events in the San Antonio River (Chapter 3), data collection should continue for at least 10 years to ensure that the effects of the treatment are tested after at least one major flood event (Kondolf and Micheli 1995). Data collection need not be every year, however collection should continue in the immediate years following treatment and after a defined threshold flood event (Kondolf and Micheli 1995). This threshold, or “effective discharge,” can be estimated using discharge records from the US Geological Survey gauge on Interlake Road (site 11149900) and the baseline geomorphic data (Shields et al. 2003).

Incorporate and adaptive management approach

Documentation of restoration planning, actions, and environmental response, whether determined successful or not, is critical for developing further conservation strategies and using an adaptive management approach to arroyo toad habitat restoration at FHL (Kondolf 1995). Every effort to improve breeding habitat regardless of scale, should be regarded as an opportunity to gain vital information about the San Antonio River behavior and thus be treated equally when considering pre- and post-treatment monitoring evaluation of the habitat at the project site. Not only will such documentation aid FHL, but it may provide direction for other arroyo toad habitat restorations projects outside of the installation.

Summary and Conclusion

FHL has been protecting the arroyo toad from adverse installation activities since the discovery of the species in 1996, and continues to improve conservation and protection strategies. In this unique situation at FHL, simply fencing off the habitat will not serve to protect the species; the species needs suitable habitat restored in areas where human activities have resulting in loss or degradation of breeding habitat. Natural vegetation succession and stream stabilization is replacing the once braided system with narrow, incised channels and deep pooling regions more suited for bullfrogs. Unfortunately halting succession is not an easy fix. Maintaining the system to favor arroyo toad breeding habitat will likely be an ongoing effort. The installation may need to experiment with various techniques to find one that is effective yet has low impact to arroyo toads. However it is certain that conservation and recovery of the arroyo toad population at FHL will not be achievable without active vegetation and stream management.

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