An Assessment of the Known and Potential Impacts of Feral Pigs (*Sus scrofa*) in and near San Diego County with Management Recommendations

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Front cover photo: pig rooting area, San Diego County (photo by N. Weflen)

Summary

This report assesses potential impacts of feral pig populations in southern California (San Diego, Riverside, Imperial, and Orange counties) and Baja California, with an emphasis on San Diego County. We compiled information on the status of pigs in these areas from the literature and interviews with numerous individuals knowledgeable about feral pig populations, including a population recently introduced into San Diego County. We also reviewed available information on the potential impacts of feral pigs on natural resources, water systems, agriculture, and human health, and discussed the feasibility of various control and eradication options.

We developed population and habitat suitability models for feral pigs in San Diego County to examine the potential for numeric and geographic expansion following the recent introduction near El Capitan Reservoir. The models suggest that the population has the potential to grow rapidly and expand into large expanses of currently un-occupied habitat. Such expansion could harm natural biological resources, including riparian and oak woodland communities and numerous sensitive species. It is possible that populations could establish in such protected lands as Cuyamaca Rancho State Park and Volcan Mountain Preserve, as well as various wilderness areas. This could greatly diminish and possibly nullify large conservation investments already made in this region, including habitat restoration efforts. Finally, an expanding feral pig population in San Diego County could invade and cause grave damage in Baja California, where feral pig populations have not, to date, been reported.

Although feral pigs in San Diego County have the potential to spread rapidly, the population is still relatively small and geographically confined. We therefore recommend initiating a pig eradication program as soon as possible. To be successful, however, an eradication program must be preceded by careful planning, coordination, and securing of funding commitments. These efforts should focus on meeting the following conditions (Parkes 1990):

1. There must be no refugia where active pig removal is not allowed. The entire population must be subject to management.
2. There must be no possibility of recolonization. Intentional reintroduction by humans must be prevented.
3. Sufficient funding must be available to maintain eradication activities at a scale and intensity that will remove animals faster than they reproduce.
4. Those attempting eradication must believe that it is possible. This will influence the chance of meeting conditions 1 and 3.

If initial assessments determine that these conditions can not be met, a feral pig control (as opposed to removal) program should be initiated to minimize pig expansion and impacts. However, when choosing between removal versus control efforts, we recommend weighing the long-term costs of pig damage and control efforts versus the shorter-term costs of a quick, successful eradication program. Immediate investments in eradication will likely be more successful in protecting sensitive resources and reducing long-term management costs.

1. Introduction

1.1. Project Need

Feral pigs (*Sus scrofa*), native to Eurasia and North Africa, have become one of the most widely distributed and rapidly expanding species in the world (Oliver and Brisbin 1993). Where they are not native they can have significant ecological impact, and so have become the topic of numerous studies and management programs as biologists and managers attempt to understand and minimize their adverse effects. Numerous control and eradications efforts are underway, where control involves maintaining populations below some threshold, and eradication strives to eliminate populations entirely.

Feral pigs have become widely established throughout much of California, where a mild climate and an extensive and diverse natural landscape provide them with abundant resources and suitable habitat. California's feral pigs, sometimes also referred to as "wild pigs," are descendents of domestic pigs kept by Spanish settlements in the late 1700s and Eurasian wild boars introduced in the 1920s and 1950s (Pine and Gerdes 1973, Mayer and Brisbin 1991). Although feral pigs have been present in California for many years, they have continued to expand their geographic range and population size. By the early 1980s, feral pigs had spread to 33 of California's 58 counties, and were estimated to number between 70,000 and 80,000; by 1996 feral pigs were documented in 49 counties, and the population was estimated at over 133,000 individuals (Waithman et al. 1999).

Feral pigs are a popular game species in California, and are officially recognized as a game mammal by the State (Waithman et al. 1999). However, serious concerns exist regarding expansion of this introduced species, because pig populations can have significant negative impacts on native species and ecosystems via direct foraging impacts, competition, spread of invasive plants, and possible disease transmission. Serious concerns also exist about damage to the State's agricultural industry and the potential of pigs to harbor and spread human diseases.

In the mid 1990s, southern California was estimated to support only 1% of the State's feral pig population, and San Diego County was considered free of feral pigs, along with neighboring Orange and Imperial counties (Figure 1; California Department of Fish and Game [CDFG] 2008). These counties were also reported to support relatively few (or no) pigs during 2004-2006 (Sweitzer et al. 2007). Riverside County, to the north, was estimated to support a low density of pigs.

This situation changed, however, when a small group of pigs was released in San Diego County approximately 3-5 years ago. The presence of these free-ranging pigs in San Diego County raised concerns about their potential spread, both numerically and geographically, and their potential impacts on the region's unique natural ecosystems. Of particular concern is the threat that an invasion of feral pigs poses to the significant public and private investments that have been made to conserve native species and lands throughout the region.

1.2. Project Objectives and General Approach

The goal of this project was to provide an assessment of feral pigs in San Diego County, including the potential for population expansion, impacts of such an expansion, and potential control options. Our first objective was to describe the status (abundance, distribution, and recent spread) of feral pigs in San Diego County based on existing information. Although the focus was San Diego County, we also sought documentation of feral pig occurrence in neighboring counties and in Baja California, Mexico (Figure 2). Our objectives also included (1) describing the potential for expansion of the San Diego County pig population, both numerically and geographically, (2) summarizing the potential impacts of such an expansion on native species and ecosystems, and (3) discussing the feasibility of various control and eradication options.

We compiled existing information on the impacts of feral pigs on natural resources, water systems, agriculture, and human health (Section 2). We also compiled all available information on the status of pigs in the study area (Section 3). In addition to reviewing all pertinent reports and publications, we solicited information concerning pig observations, pig history in the areas, and management and control considerations from agency personnel, biologists, local residents, landowners, and hunters (see Appendix A for the list of individuals contacted).

We also examined the potential numeric and geographic expansion of the San Diego County population by developing a population growth model and a habitat model, respectively (Appendix B, Section 4). Our intent was to generate and examine scenarios of how this population may grow during a 10-20 year period, and to identify those geographic areas where colonization is most likely. Based on the results, we discuss the potential impacts to natural resources, agriculture, and human health in San Diego County (Section 5) and possible control measures and related considerations (Section 6). Finally we provide general recommendations for pig management in San Diego County.

2. Potential Impacts of Feral Pigs

It is well accepted that introduced (non-native) species can have significant negative impacts on native species and environments, and often also on agricultural resources. Negative impacts may result from predation or consumption of native species, direct or indirect competition, disruption of natural food webs, transmission of diseases, or alteration of habitat conditions.

Feral pigs possess a number of characteristics that make their impacts to the environment and native species particularly worrisome. First, they can use a wide variety of habitats, from tidal marshes to mountain ranges. Although they prefer areas with heavy cover and abundant food sources, such as mast-producing oak woodlands, they will also use dense shrub habitats, open range, pastures, and agricultural fields, especially at night in areas where human disturbance is low.

Second, pigs are omnivores who will eat anything from grain to carrion, so there is potential for adverse impacts on diverse communities and species via consumption, competition, and other processes. In California, acorns are a primary forage item, but pigs will also feed on underground plant material, water-submerged vegetation, agricultural crops, invertebrates, fish, and even domestic lambs, goat kids, and calves (Pavlov et al. 1981, Barrett and Birmingham 1994). Pigs can grow to be quite large, with mean body weights in some populations reported to reach 92 kg (202 pounds) and 114 kg (251 pounds) for females and males, respectively (Sweeney et al. 2003), so they consume substantial amounts of food. Additionally, their feeding activities are disruptive to the environment (discussed in greater detail below).

Finally, pigs have a high reproductive rate (Barrett and Birmingham 1994; Appendix B) and their populations can expand rapidly, allowing them to be good colonizers.

2.1. Impacts to Natural Ecosystems and Water Systems

Direct Impacts

The foraging and wallowing behavior of feral pigs has direct negative impacts on a variety of native plant and animal species. Feral pigs are known to directly consume a variety of plant and animal species (Loggins et al. 2002, Schley and Roper 2003) and have been implicated in the decline of such sensitive species as green sea turtles (*Chelonia mydas*; Green 1981), Hutton's shearwater (*Puffinus huttoni*; Cuthbert 2002), and the dark-rumped petrel (*Pterodroma phaeopygia*; Cruz and Cruz 1996) via the consumption of eggs. Feral pigs have also been documented to prey upon small ungulates (Pavlov et al. 1981) and small mammals (Wilcox and Van Vuren 2009), so may act as an additional and novel predator in native ecosystems.

Pigs feeding under oaks, San Diego Co. (Photo by N. Weflen)

Pig feeding activity directly damages tree seedlings and limits tree generation (de Nevers and Goatcher 1990, Sweitzer and Van Vuren 2002). Tree damage has been substantial enough to cause concern among foresters in the southern and western United States (Barrett and Birmingham 1994). A perhaps less obvious but substantial impact to forests is consumption of acorns. The distribution of feral pigs in California is focused in oak-dominated habitats (CDFG 2008), and acorns are their primary food item in most areas. Pigs are found in large congregations in oak forests when acorns fall, and their movements are reduced when they focus on this significant forage item. When acorn supplies decline, pig home ranges increase and their diets become more diverse (Barrett and Birmingham 1994). Such focused consumption and associated rooting reduces regeneration of oak forests (Sweitzer and Van Vuren 2002) which, in turn, can have multiple indirect effects (see *Indirect Impacts* below).

Pigs rely on water sources for drinking and thermoregulation. They do not have functional sweat glands and must therefore cool themselves in water and mud. For this reason, their distribution is often focused around lakes, ponds, streams, seeps, and springs, particularly in hot climates or seasons. At these locations, wallowing, trampling, and churning of water and mud can harm water quality and quantity, cause streambed erosion, reduce riparian habitat quality, and impact water systems (discussed in greater detail below).

Indirect Impacts

Pig activity can also have numerous indirect impacts on natural areas and native species. Their rooting activities have been shown to alter soil properties (Lacki and Lancia 1983), reduce cover of herbaceous plants and shrubs (Bruinderink and Hazebroek 1996, Welander 2000), and cause unnatural disturbance regimes (Kotanen 1995), all of which can disrupt natural plant communities. Pig activity can increase incidence of alien grasses (Aplet et al. 1991) and disrupt soil microarthropod communities (often used as an indicator of soil condition; Vtorov 1993).

Pigs also compete with native species for limited forage items (Ilse and Hellgren 1995, Laurance 1997). One study revealed that feral pigs actively seek out and consume acorn hoards collected by small animals (Focardi et al. 2000), thereby potentially impacting oak regeneration as well as native small mammals. Damage to oak woodlands and a decline in regeneration of oaks can have large and far-reaching environmental implications. In California, oak woodlands play an important role in maintaining watersheds, provide habitat for over 3500 species of vertebrates and invertebrates, and provide a setting for human recreation (Garrison and Standiford 1996, Pavlik et al. 1991). Oak woodlands are threatened by agricultural and urban development, disease, and very low recruitment. Additional negative impacts from feral pigs further threaten this important vegetation community, thereby threatening entire watersheds and the habitat of thousands of animal species.

The presence of pigs can also disrupt predator-prey relationships among other species. On the Channel Islands of California, the presence of feral pigs was identified as a key factor in the near extinction of Channel Island foxes (*Urocyon littoralis*), an endemic and Federally listed species. Their presence provided an unnatural food source which subsidized golden eagles (*Aquila chrysaetos*) not native to the islands, and these predators in turn nearly drove the fox population to extinction via unnatural predation levels (Roemer et al. 2001).

Pigs may alter entire ecological communities via their activities. Kaller and Kelso (2006) found that presence of pigs altered the invertebrate and microbial communities in a coastal watershed in Louisiana. Follow-up studies by Kaller et al. 2007 found that aquatic biota, such as freshwater mussels and aquatic insects, were reduced in stream reaches with pig activity. The authors concluded that the feral pigs could be the cause of this decline, supported by the finding that increased levels of coliform bacteria in the stream reaches were genetically linked to pigs in the watershed. Kaller and Kelso (2006) also noted that freshwater aquatic biota may have been impacted by pigs via organic enrichment of the water (from feces). It is also possible that pig rooting and wallowing increased particulate matter in the water and that this negatively impacted the native aquatic biota. Kaller et al. (2007) cautioned that feral pigs can adversely affect aquatic resources in a number of ways, and noted that the risk would be particularly great for already stressed ecosystems.

Pig activity can also damage downstream water resources because rooting causes soil disturbance and vegetation loss, both of which can increase erosion and sedimentation rates. In addition to impacting native aquatic systems, this can impact downstream water quality and quantity, such as human water supplies. If pigs are present in adequate numbers, they may also contaminate water sources with disease vectors that can impact agricultural resources, native wildlife, and human health.

Pig foraging sign in streambed, San Diego Co.(photo by G. Reece)

2.2. Impacts to Agriculture

Pigs can extensively damage agricultural resources, creating substantial costs to farmers. One of the most common sources of damage is rooting, which results in damage to crops, pastures, farm ponds, and livestock watering holes, and causes soil erosion (Barrett and Birmingham 1994). Frederick (1998) reported, that economic losses from pig rooting alone were estimated at $1.73 million in one year for 40 surveyed counties in California. Pigs have also been known to damage residential lawns, golf courses, fences, and farm structures such as small animal pens (Barrett and Birmingham 1994).

Predation on livestock is apparently a less common problem but can be substantial. In 1991 pigs in Texas and California were reported to have killed 1473 sheep, goats, and exotic game animals, based on reports by producers to the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (Barrett and Birmingham 1994).

Pigs also harbor diseases that can damage agricultural resources. Feral pigs were suspected as one possible source of the 2006 *Escherichia coli* (*E. coli*) O157:H7 outbreak associated with consumption of spinach grown in California (Kreith 2007), which caused spinach growers substantial economic losses. Pigs also increase the risk disease transmission to livestock, because they can be a potential reservoir for such diseases as cholera, swine brucellosis, trichinosis, bovine tuberculosis, foot and mouth disease, African swine fever, pseudorabies, and leptospirosis, all of which are transmittable to livestock (Wood and Barrett 1979, O'Brien 1989, Vengust et al. 2008). For example, bovine tuberculosis was transmitted from feral pigs to beef cattle in California in 1965, and pork infected with cholera led to the decision to cull all captive and feral pigs on Kosrae Island in the eastern Caroline Islands (Barrett and Birmingham 1994).

Drew et al. (1992) conducted a retrospective serologic survey for brucellosis in eight wildlife species in California, including wild pigs, black bear, and six ungulate species. With the exception of wild pigs, the authors concluded that brucellosis would not be an important wildlife health problem for the species surveyed during their study period (1977 to 1989). Wild pigs, in contrast, had the highest percentage of reactors, suggesting that they could act as an important reservoir for this disease. Drew et al. (1992) concluded that brucellosis in pigs, even at the rate detected, could have epidemiological implications for both humans and livestock. In the cattle industry, brucellosis causes abortions, infertility, death of young calves, decreased milk production, and other health problems (Edmondson et al. 1999). It is considered one of the most serious diseases of livestock in California because it spreads rapidly and can be transmitted to humans (California Department of Food and Agriculture 2009). The state of California has invested heavily in eradicating this disease from the State's domestic livestock, so presence in feral pigs is a concern.

2.3. Human Health Concerns

Feral pigs may carry and transmit a number of human pathogens, including viruses, bacteria, and parasites. California Department of Fish and Game therefore advises hunters to take special precautions to reduce transmission of disease, such as trichinosis and brucellosis, during handling and processing of pig carcasses, because these diseases are potentially transmittable to humans, livestock, pets, and wildlife (Waithman 2001). In the Brazilian Pantanal feral pigs were found to play an important role in maintenance of the flagellate protozoan *Trypanosoma cruzi*, which causes the human disease "Chagas disease" (or "American trypanosomiasis"; Herrera et al. 2008). This disease has been documented to occur in Mexico, Central America, and South America.

Feral pigs can also present a human health risk indirectly, by contamination of agricultural produce or water sources. As mentioned above, Keith (2007) noted that wild pigs were suspected as one possible source of the 2006 *E. coli* outbreaks associated with consumption of spinach grown in California. Given the propensity of feral pigs to focus their activities near water and riparian habitats, they may also serve as a nonpoint source of surface water contamination. Atwill et al. (1997) detected the shedding of *Cryptosporidium parvum* oocysts and *Giardia duodenalis* cysts among pig populations in California, and concluded that feral pigs may serve as a nonpoint source of protozoal contamination of water sources. These authors noted that although the zoonotic potential of *C. parvum* is not well understood, there is strong evidence that it is infectious to humans and, although the zoonotic potential of *G. duodenalis* from domestic, wild or feral mammals to humans is inconclusive, much of this uncertainty is due to ongoing confusion about taxonomy of this organism. Atwill et al. (1997) concluded that, because pigs were found to shed both organisms, and that they are abundant in western California, it would be possible under appropriate environmental conditions for feral pigs to contaminate nearby surface waters. Further, this risk would increase with increasing densities of pigs because there would be more pigs per area unit shedding, and individuals in dense populations tend to shed more than those in low-density populations (Atwill et al. 1997). The authors noted that although elk (*Cervus elaphus*) in California are also known to shed *C. parvum*, their distribution is less tied to water, so they would be less likely to contaminate water sources than pigs.

Kaller et al. (2007) used genetic tracking to link waterborne coliform bacteria collected in a Louisiana watershed with bacteria from feral hogs living in the same watershed. Their analyses indicated that pig activity levels were associated with increased waterborne bacteria levels, which often exceeded state and federal surface water guidelines. Genetic analyses did not indicate a link between these elevated bacteria levels and other species found in the area, such as deer, turkeys, beavers, or horses.

The risk of water contamination depends on the number (or density) of pigs using a particular water source or watershed, because increased density of pigs leads to increased transmission and shedding rates. Risks may also increase in hot dry climates, because pig use of water sources is likely higher than in cooler, wetter climates.

An additional public safety concern that has been voiced is that presence of pigs may increase poaching on lands where hunting is not legal (Sweitzer and McCann 2007), thereby making the lands less safe for other uses (e.g., recreational activities).

2.4. Monetary Impacts

Feral pigs can cause substantial monetary impacts. Cost estimates of control and eradication programs are typically the most cited economic impacts, and are perhaps the easiest to quantify. For example, the National Park Service spent $1.5 million to construct a pig-proof fence around Pinnacles National Monument in central California. They allocated $844,000 to eradicate pigs within the fenced area, and they have spent approximately $55,000 annually to maintain the fence (Kreith 2007). Monetary impacts to agricultural resources can also be extensive and can be estimated in some situations. For example, as mentioned above, one estimate of economic losses from pig rooting alone was $1.73 million dollars in one year, based on a survey of 40 counties in California (Frederick 1998). Kreith (2007) pointed out that although the monetary impact on agriculture may be considered small in relation to the overall economic activity of agriculture in California, the additional potential costs could be significantly higher if diseases carried by pigs were to impact livestock or food crops.

Economic costs associated with impacts to natural resources are difficult to estimate, and they may therefore not be included in economic impact assessments. Sweitzer and McCann (2007) noted that the cost of pig damage will continue to be underestimated until there is a better method of estimating the monetary value of natural lands and resources. Damage to these lands can result in costs associated with damage to sensitive habitats or species, as well as declines in visitor experience, and these costs should be considered in the assessments of the monetary costs of feral pigs.

In some cases the presence of pigs can be seen as economically beneficial. For example, pigs can be an asset to landowner who charge a hunt fee (Adams et al. 2005). During the past 10 years, CDFG made between $340,000 and $877,000 annually from the sale of pig hunting tags (CDFG unpublished data, www.dfg.ca.gov/licensing/statistics/statistics.html). However, the state also invests a great deal of resources in pig management, and it is unknown if profits from tag sales can offset the cumulative costs of management, damage to agricultural resources, and the extensive but difficult to quantify impacts to natural resources.

3. The History and Current Status of Pigs in Southern California

3.1. A Brief History and Status of Feral Pigs in California

Pigs were first introduced to the continental United States in 1593 and, as of 1994, occurred throughout the southeastern United States, from Texas east to Florida and north to Virginia, and in California, Hawaii, Puerto Rico, and the Virgin Islands (Barrett and Birmingham 1994, Sweeney et al. 2003). They are the most abundant free-ranging introduced ungulate in the United States (Mayer and Brisbin 1991).

Feral pigs have inhabited California since the late 1700s, when domestic pigs were free-ranged near coastal Spanish settlements to forage on acorns in nearby oak woodlands (Pine and Gerdes 1973, Mayer and Brisbin 1991). Subsequently, these pigs interbred with Eurasian wild boar that were released in Monterey County in 1925 and then in other parts of California in the 1950s (Mayer and Brisbin 1991). By the early 1980s, feral pigs had spread to at least 33 of California's 58 counties, with an estimated 70,000 to 80,000 pigs in the state (Mansfield 1986). Waithman et al. (1999) used hunter tag returns to estimate pig numbers and range expansion in California, and estimated that approximately 133,000 feral pigs occurred in the state in 1996, and that pigs had expanded to a total of 49 of the state's counties. Sweitzer and McCann (2007) estimated that pigs were found in appreciable numbers in 47 counties, with smaller numbers in an additional 2-3 counties during 2006-2007. Although the potential rate of geographic range expansion is not known, feral pigs in California were documented to expand their range from relatively few coastal areas in the 1960s to approximately 25% of the state's total land area by 1996 (Waithman et al. 1999).

Although much of the historic spread of pigs in California was likely due to natural range expansion, it was likely accelerated by intentional releases for hunting opportunities, as well as release of animals by farmers no longer interested in producing pigs commercially (Waithman et al. 1999). Increased forage resources from expanding agricultural operations, such as from irrigated agricultural fields, also likely helped pigs expand their range in the state (Waithman et al. 1999). In addition, it has been hypothesized that interbreeding with Eurasian wild boars may have facilitated additional range and population expansion after the 1920s due to enhanced adaptive abilities (e.g., adaptation to more extreme temperatures and limited water; Waithman et al 1999). In California, although mountain lions (*Puma concolor*), black bears (*Ursus americanus*), coyotes (*Canis latrans*), and bobcats (*Lynx rufus*) are capable of preying on feral pigs, the impact of predation on feral pig populations is not well understood. One study conducted in the Diablo Range in northern California indicated that lion diet consisted of 5-38% feral pigs depending on season (Hopkins 1989)

Feral pigs have been recognized as a game mammal by the State of California since 1956, resulting in partial protection from eradication efforts in the state (Waithman et al. 1999). Several regulations govern pig management on public and private lands. Sections 4181 and

4181.1 of the California Fish and Game Code describe provisions that allow the taking of pigs causing damage to private property with a CDFG-issued permit. In addition, public agencies can develop a Memorandum of Understanding with CDFG allowing them to remove pigs from their lands. Concern over negative environmental and agricultural impacts from feral pigs led to 1992 legislation requiring pig hunters to purchase a "pig tag" in addition to a hunting license. Portions of the pig tag must be returned to CDFG to provide details concerning the pig hunt (such as where each pig was taken). Funds from the purchase of pig tags are directed to support research to guide feral pig management (Waithman et al. 1999).

3.2. Feral Pigs in Southern California

Southern California has historically been inhabited by very low numbers of feral pigs (Figure 1; Sweitzer and McCann 2007, CDFG 2008). In this section, we present the known status of pigs in four southern California counties: Riverside, Orange, Imperial, and San Diego. To our knowledge, no research or surveys have been conducted to assess the distribution or abundance of pigs in these counties, and we found very little information on their history or current status. Pigs have been reported in all four counties, but numbers may be very low in three of these counties (Figure 3). Feral pig hunt tags collected by CDFG during 16 years (1992 – 2007) indicate that Riverside County has been inhabited by at least one established pig population for some years, and that the remaining three counties were likely inhabited by low numbers of pigs, if any, during this period (Table 1; CDFG unpublished data). Hunt tag data may, however, underestimate the distribution or abundance of feral pigs because some areas inhabited by feral pigs may not be open to public hunting or may provide poor access for hunters.

Table 1. Number of hunter pig tags returned from four southern California counties during 1992-2007[a] (CDFG, unpublished data).

County	Year (1992-2007)															
	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07
Riverside	6	3	20	13	6	11	10	15	17	4	10	6	1	3	7	7
Orange	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Imperial	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
San Diego	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

[a] Pig tag information for 2008 and 2009 are not yet compiled by CDFG.

The following summaries for individual counties were compiled using information obtained during interviews with individuals listed in Appendix A, unless otherwise indicated.

San Diego County

San Diego County has been inhabited by one known population of pigs for approximately the past 3-5 years near the Capitan Grande Indian Reservation and the El Capitan Reservoir, the latter owned and managed by the City of San Diego. The exact date of introduction and whether these animals had escaped captivity or were released purposefully is unknown. However, there is speculation that the animals may have been released for hunting purposes. Some sources reported that up to 20 pigs may have been released during approximately 2004-2006, and that the released group included both males and females.

In recent years, these pigs have frequently been observed on San Diego City lands along the El Capitan Reservoir. Observations of pigs or their sign (tracks, rooting, wallows) have also been made north of the reservoir, along the San Diego River drainage, near the intersection with Cedar Creek, and to the east of the reservoir in Conejos Creek, Sand Creek, and areas just south of Boulder Creek. Pigs have also been reported at the northern edges of the town of Alpine. There are no data on the current size of this population, but several sources felt that there may now be up to 100 pigs. Observed groups have been relatively large, with one report of a group of 54 animals, and several groups were observed to include young piglets.

Pig impacts have not been measured or evaluated, but casual observations have documented signs of wallowing in the San Diego River drainage and extensive rooting and damage to vegetation in nearby shrub, woodland, and grassland habitats in areas north and east of the reservoir. One source reported exposure of Native American artifacts in areas where pigs had been rooting under oak trees, thereby placing these items at risk of damage or collection.

It is possible that this population of pigs is hunted on Tribal lands, under the authorization of the Barona and Viejas tribes, but the number of animals removed from Tribal lands is currently not known. Hunting is prohibited on San Diego City lands at the reservoir, but legal hunting is possible on private lands and on some public lands, such as National Forests, with appropriate license, tags, and landowner authorization. The one hunter pig tag returned to CDFG for San Diego County during 1992-2007 indicated that a pig was shot north of Lake Morena in 2006, but further locational details were not provided, and it is not known if this pig originated in the Capitan Grande population.

One additional San Diego County sighting of pig sign was reported in the late 1990s in the Agua Tibia Wilderness, at the northern edge of the county. This was followed by a report of a hunter killing a pig in the same general area a few years later. No subsequent pig observations were reported for this area, and no hunter tags have been returned, suggesting that these observations represented a release or escape that did not result in an established population.

Riverside County

Feral pigs in Riverside County tend to be distributed in two general areas: (1) the Prado Basin and Santa Ana River corridor, and (2) San Timoteo Canyon and nearby canyons. Pigs are also held and hunted at a private fenced ranch (Bighorn Canyon Ranch) in Bighorn Canyon, just outside of Moreno Valley near San Timoteo Canyon. This distribution of feral pigs is in general accordance with the distribution described by CDFG in 1997 (Figure 1; CDFG 2008). No surveys or studies have been conducted to describe the distribution in greater detail. Hunter tags provide some indication of pig locations, but they are often very general and they are only representative of locations that hunters have access to. Nevertheless, they do provide some indication of pig presence. In Riverside County, for example, outside of the private ranch in Bighorn Canyon, the majority of tags were returned from San Timoteo Canyon, Redlands, and Morena Valley (CDFG, unpublished data).

Pigs have been in the Prado Basin (owned and managed by the Orange County Water District) and along the Santa Ana River north of the basin since at least the 1960s. It is thought that they escaped or were released from nearby farms or ranches when this was a more rural area. It is believed that their distribution is restricted to the river drainage, and that their greatest densities are near Hidden Valley Wildlife Area, upstream of Prado Basin and just east of Norco. This wildlife area is owned by CDFG and managed by Riverside County. According to individuals interviewed for this project, pig distribution along this stretch of the Santa Ana River appears to be associated with thick stands of giant reed (*Arundo donax*), and extensive stands of *Arundo* in the Hidden Valley Wildlife Area are believed to provide cover and protection for the pigs.

Management of the Prado Basin/Hidden Valley population of pigs has been limited. There is currently no established management plan for pigs in this population, although the need to develop one was voiced by several individuals interviewed for this project. CDFG has responded to multiple complaints of pigs damaging private lands such as golf courses and a turf farm, and most of CDFG activities related to pigs have been in response to such depredation cases. A hunting program, limited to archery, was established on CDFG land in the 1990s but discontinued for unknown reasons after one season. It is unknown if this population is expanding, declining, or stable, although two sources indicated that illegal (and therefore undocumented) hunting may be limiting the population to some extent.

Pig impacts to natural resources in this area have not been measured or documented. One source suggested that they may not cause extensive damage to the native ecosystem because they tend to be found in association with dense non-native stands of *Arundo donax*. However, it is very likely that their feeding activities have negative impacts on natural habitats, or that they may hinder restoration efforts. For example, efforts are underway to restore habitat for Least Bell's Vireo along the Santa Ana River, including the Prado Basin. These efforts, which include removal of *A. donax* and establishment of native riparian vegetation, may be hindered by the presence of pigs if newly planted native vegetation is destroyed by their foraging and rooting. Pigs in this population are believed to be primarily nocturnal, so opportunistic sightings may underestimate the extent of their habitat use.

Information on pigs in the San Timoteo Canyon area is scant. CDFG personnel believe that the population is smaller than the Prado Basin/Hidden Valley population, although greater number of pig tags were returned from the San Timoteo area, possibly due to greater hunter access and opportunities for legal hunting. Based on information provided to CDFG via pig tags, the majority of pigs in this area were hunted on private property. There is little information about pig impacts in this area, although some complaints have been filed with CDFG, primarily related to pigs rooting on private property. It is believed that small amounts of oak woodlands as well as apple and cherry orchards (such as near Cherry Valley) provide some forage opportunities, and that problem pigs may have been taken without filing a depredation complaint with CDFG (i.e., the pig may have been taken illegally). There is no detailed information on abundance, distribution, or population size trends for pigs in this area.

It is not known if the two Riverside County pig populations are connected by occasional movement of animals. The two occupied areas are connected by approximately 28 km (17.4

miles) of the Santa Ana River (Hidden Valley Wildlife Area to the base of San Timoteo Canyon), which is well within known dispersal distances of pigs (55 km; Lapidge et al. 2004). However, stretches of altered riverbed likely reduces the chances of dispersal along this corridor. It is not known whether any of the feral pigs in San Timoteo Canyon are escapees from the Bighorn Canyon Ranch, but this is a possibility.

Orange County

Orange County is apparently occupied by very few pigs, which is consistent with a very low rate of hunter tag returns (Table 1). Pigs in this county may be found along the Santa Ana River west of the Prado Dam (and south of Chino Hills), and likely belong to the Prado Basin population. Although it is not known how far west (downstream) pigs from the Prado Basin may travel, it is unlikely that they could move into Orange County beyond the Coal Canyon area before being stopped by dense urban areas to the west. No abundance estimate exists for this area, and no other populations were reported for this county.

Imperial County

Imperial County is also inhabited by low numbers of pigs. One source reported that a small population historically existed along the Colorado River just south of Walter's Camp, but that these animals disappeared by approximately the mid-1970s. A pig release was reported to have occurred in the Trifolium Drain area of the Imperial Valley, along the southwest shores of the Salton Sea, in 1939, but these animals apparently were gone by 1954.

More recent sightings indicate that pigs are present once again along the Colorado River (or that pigs have been present but undetected since the 1970s). Pigs have occasionally been observed by CDFG personnel during recent aerial waterfowl surveys. During these opportunistic observations, pigs were observed on both sides of the river and in backwaters as well as standing on sand bars in the river. Sightings were all north of Picacho State Recreation Area.

No surveys have been conducted to determine the full distribution or size of this population, but opportunistic observations by CDFG staff suggest that numbers may be increasing along the river. Most observations of pigs were in areas heavy with invasive tamarisk (*Tamarix* spp.), and pigs were reported to use this invasive species as cover. It is unlikely that pigs in Imperial County could expand their range or exist permanently far from the river. Although forage is available in the extensive agricultural fields of the Imperial Valley, the desert heat, lack of dense cover, and lack of water would make these areas inhospitable to pigs. We are not aware of any reported complaints from nearby farmers in the Imperial County.

The extent of pig impact along the river has not been assessed. It is possible that pig foraging and wallowing has a negative impact on riparian habitats and species (e.g., ground-nesting birds, amphibians, mesquite trees) as has been reported in other regions.

Although a general management plan exists for the State of California (Waithman 1995), there are currently no management plans specifically designed for the above populations.

3.3. Feral Pigs in Baja California

We reviewed available literature and solicited input from biologists (Appendix A) regarding the presence of feral pig populations in northern Baja California. We were unable to find documentation of any known populations, suggesting that this region may not be inhabited by feral pigs. One concern of a population expansion of feral pigs in San Diego County is the potential for it to lead to an invasion into Baja California.

4. The Potential Expansion of Pigs in San Diego County

We modeled the potential for numeric and geographic expansion of the San Diego County pig population during a 10- and 20-year period following introduction. Our intent was to examine conservative scenarios of how this population may grow in the near future, and to identify those geographic areas where one might be most likely to find pigs as the population grows. As described in Appendix B, we intentionally kept our modeling approaches simple because we do not have adequate information specific to pigs in this area to develop complex models. We therefore based our models on published information and expert opinion, and modeled the growth of the population using population parameters reported for other feral pig populations. We first generated population estimates for 10 and 20 years from the time of release, and identified suitable habitat in our study area. We subsequently compared these model results in the context of known pig spatial use patterns (e.g., density and dispersal distances) to evaluate how much and what portions of the landscape the expanded population might potentially use.

4.1. Population Growth

We do not know the exact size or composition of pigs released in San Diego County, but some sources reported that up to 20 animals, including males and females, may have been released. We therefore began our simulations of population growth with a total of 10 females (8 adults, 1 yearling, and 1 juvenile), and simulated population growth with a Leslie matrix model (Leslie 1945, 1948), following the approach used by Bieber and Ruf (2005) in their simulations of feral pig population growth (Appendix B).

Simulation results suggested that the pig population in San Diego County could grow substantially under moderate[1] environmental conditions . The stochastic model, which simulated only the female component of the population and assumed an even sex-ratio (Appendix B), suggested that the population may grow even under poor environmental conditions (based on survival and reproduction rates observed in other populations during poor environmental conditions; Bieber and Ruf 2005). Under poor conditions, mean simulation results indicated that the number of females may grow to 22 and 30 by Year 10 and Year 20, respectively, with some simulations reaching 56 and 159 females by years 10 and 20, respectively (Appendix B). Under moderate conditions, model simulations suggest a population growing much more rapidly, with a

[1] Poor, intermediate, and good environmental conditions are assumed from demographic data that exhibit low, med, and high reproductive and survival rates, following Bieber and Ruf 2005.

mean female population of 487 and 13,829 by year 10 and 20, respectively, with some simulations peaking at more than 880 and 26,000 females at year 10 and 20 years, respectively.

Although we do not know the actual population parameters (e.g., survival and reproduction rates) of the population in San Diego County, model results appear to be plausible for the initial years of simulation. At Year 4, model simulations indicated a mean of 18 females (with some simulations reaching 46 females) under poor environmental conditions. Under moderate environmental conditions, the mean number of females at Year 4 was 65, with at least one simulation reaching 119 females. Although no empirical population estimate exists for this population, the observation of a single group of 54 animals suggests that the population has been growing *at least* at the low model rates, if one assumes an equal sex ratio.

Our model did not incorporate the influence of population density, and it is likely that population growth would slow in future years if reproduction and/or survival rates are density dependent. However, it is very likely that the population can expand to currently unoccupied habitat, thereby delaying the potential impacts of density dependence, and that food resources (e.g., acorns) would be significantly impacted by the time the population was limited by the influence of density. Regardless of the population's current growth rate, it is likely that San Diego County's pig population will expand to new areas and grow to a much larger size before reaching densities at which density factors come into effect.

4.2. Geographic Range Expansion

To examine to potential geographic spread of feral pigs in San Diego County, we developed a habitat suitability map for an area encompassing a radius of 120 km from their current location near El Capitan Reservoir (Appendix B). This distance, which is approximately double the maximum dispersal distance reported for pigs (Lapidge et al. 2004), allowed us to examine suitability across all of San Diego County and the U.S. Peninsular Ranges (Figure 2).

According to the model, extensive pig habitat exists in the study area (Figure 4). Approximately 3,620,000 acres (14,645 km^2) are rated as having at least medium suitability (with a rating of ≥ 0.50), and approximately 1,123,000 acres (4,545 km^2) were found to have very high suitability (with a rating ≥ 0.75). Pig habitat is found primarily in the mountain regions of the study area, with inhospitable habitat in the deserts and in urbanized areas along much of the coast.

The feral pig population near El Capitan has the potential to expand to extensive unoccupied habitat that is contiguous with their current distribution (Figure 5). Approximately 48,458 acres (196 km^2) of the most suitable habitat is contiguous with their current location, making expansion throughout this area very likely. A much larger area of contiguous habitat has a medium suitability rating, and also provides the potential for range expansion (Figure 5). If feral pigs colonized this habitat, they could expand their range north to the San Jacinto Mountains and south into Baja California.

Extensive range expansion is likely even if feral pigs colonize and occupy only those lands assigned the highest (≥0.75) suitability rating by our model. We examined the potential dispersal of pigs across the study area by assuming that pigs can move through habitat with a rating > 0 to reach neighboring patches of high suitability habitat (Appendix B). Although pigs have been documented to move up to 55 km, feral pigs typically exhibit a strong attachment to their home ranges (Lapidge et al. 2004). Female pigs in Sweden were observed to disperse an average of 4.5 km from their natal sites, whereas males dispersed an average of 16.6 km (Truve and Lemel 2003). It is possible that at least some of these dispersal distances were across high quality habitat, and that dispersal across low quality habitat would not be as far. For example, genetic analyses of pigs in southwestern Australia, indicated that pig populations living in neighboring watercourses separated by 25 km were not commonly connected via migration (Hampton et al. 2004). We thus used a conservative dispersal of 4.5 km and a less conservative dispersal distance of 15 km across habitat with low suitability, and allowed range expansion to lands with a suitability rating ≥0.75 to proceed via a stepping-stone process (across lands with lower suitability). Regardless of dispersal distance used, our analyses suggest that pigs have the potential to spread to the northern and southern extents of our study area (Figure 6 and 7).

The patch of high quality habitat currently occupied by pigs (196 km^2) is estimated to be able to support between 137 and 745 pigs, based on observed densities in other Californian populations (Sweitzer et al. 2000; Appendix B). When using the conservative dispersal distance of 4.5 km, pigs could expand to lands totaling approximately 1,162, 1,927, and 2,928 km^2 in just the first three dispersal steps (Figure 6). These areas are estimated to be capable of supporting 813-4,416, 1,348-7,323, and 2,050-11,126 pigs, respectively, based on the range of observed densities in other California populations (Sweitzer et al. 2000; Appendix B). This suggests that habitat is available to support substantial numbers of pigs, even within a limited dispersal scenario.

In San Diego County, pigs have been observed along the San Diego River drainage several miles north of El Capitan reservoir, and have been observed to the east and southeast in areas outside of the highest suitable habitat (Figure 8), suggesting that their range expansion potential is greater than discussed above. The past spread of pigs in other portions of California appears to have followed a pattern observed among other invasive species, in which range expansion is initially slow before rapidly accelerating (Lodge 1993, Waithman et al. 1999). It is possible, therefore, that the rate of range expansion in San Diego County's pig population may exhibit an increase in coming years.

5. Potential Pig Impacts in San Diego County

Feral pigs will likely have a variety of extensive impacts in San Diego County. As discussed in Section 2, these may include direct and indirect impacts to native species, ecosystems, agriculture, and water systems. For example, the current distribution of feral pigs in San Diego County overlaps portions of Federally designated critical habitat of the coastal California gnatcatcher (*Polioptila californica californica*), as well as habitat of the San Diego thornmint (*Acanthomintha ilicifolia*), a Federally listed endemic herb found in coastal sage scrub, chaparral, and native grasslands. Pigs can impact the former via destruction of vegetation used for nesting, foraging, and cover, and the latter via direct consumption, trampling, soil disturbances, and plant community alteration. Other sensitive species that may be impacted now or as the population grows include Least Bell's vireo (*Vireo bellii pusillus*), Laguna Mountain skipper (*Pyrgus ruralis lagunae*), and Arroyo toad (*Bufo californicus*). In addition to impacts discussed in Section 2, these and other species may be impacted directly or indirectly in ways we are not yet able to predict, via alterations to the natural landscape of San Diego County's backcountry.

Feral pigs may have extensive impacts local native habitats such as oak woodlands, chaparral, and native grasslands, as discussed in Section 2. In San Diego County, impacts to native habitats may be magnified by the fact that many are already stressed from previous impacts of wildfires, drought, and degradation by humans. For example, intense consumption of acorns reduces reproduction of native oaks, increasing vulnerability of oak woodlands and the many species that rely on them (Section 2). In areas ravaged by recent wildfires, recovery via recruitment of oak seedlings (and many other plant species) could be hindered by foraging and rooting by pigs. Loss of vegetation following wildfires can increase soil erosion and slope instability, and these conditions can be exacerbated by rooting and wallowing by pigs. The presence of pigs may therefore greatly hinder recovery of our natural landscapes following wildfires.

The concentration of pigs along one of San Diego's primary watersheds and water sources is also a concern. As discussed in Section 2, an increasing population of pigs near a major water source may increase the risk of water contamination. It also threatens water quality via increased soil erosion and subsequent sedimentation of streams and reservoirs.

Pig wallow, San Diego Co. (Photo by N. Weflen)

Pigs may also threaten local cultural resources. Recent observations of Native American cultural artifacts exposed by rooting activities suggest that pigs may place these resources at increased risk of destruction, exposure to the elements, as well as potential discovery by illegal collectors.

Pigs have been observed on a mix of public and private lands, including U.S. Forest Service and San Diego City lands (Figures 8 and 9). As feral pigs expand their range, it is likely that they will become established in protected lands, where they will jeopardize the protection of native habitats and multiple sensitive species. Such areas include Cuyamaca Rancho State Park, Volcan Mountain Preserve, State and Federal wilderness areas, the San Diego River Park, and possibly the upper elevations and watersheds of Anza-Borrego Desert State Park (Figure 10). Habitat suitability patterns, published dispersal distances, and the existing opportunistic sightings of pigs distant from El Capitan Reservoir (Figure 8) suggest that movement into these areas is highly likely. The presence of pigs could impact numerous endemic and sensitive species, and jeopardize the ecological health of a region that is recognized by scientists for its high biodiversity and level of endemism. As a result, their presence would diminish and possibly nullify the large previous conservation investments made in this region.

Finally, the presence of pigs could hinder or reverse ongoing restoration efforts, such as those to reestablish native riparian habitats along the San Diego River, if pigs consume and trample newly planted native species or if their wallowing and soil disturbance negatively impacts water quality or quantity.

6. Management Options and Considerations

As a result of the negative impacts that feral pigs can impose on natural landscapes and species, most management has focused on their control and eradication. Although releases and translocations have occurred, typically to expand hunting opportunities, most programs implemented by agencies and public land owners have focused on their control or eradication. In recent years, the need for such programs has increasingly been recognized among agency biologists and land managers as pig populations and their impacts have increased (Sweitzer and McCann 2007). Sweitzer and McCann (2007) conducted a survey of natural lands managers and concluded that, in general, the presence of feral pigs in natural areas is viewed as a negative situation. However, the control of feral pig populations is a challenging management task, for the same reasons that pigs are such successful invaders (Section 2). In this section we summarize management options and considerations related to control or eradication of feral pigs.

6.1. Management Options and Challenges

A number of techniques have been used to control or remove pigs and to reduce their impacts. Non-lethal methods have been used on a number of occasions to reduce pig impacts on native landscapes, agricultural resources, and native species. These include the use of caging around seedlings in restoration projects and the use of exclusion fences around sensitive habitats (e.g. riparian areas). These options have been used successfully in California to protect entire parks or sensitive species, but costs can become prohibitive for large projects. In addition, the placement of extensive fencing can have negative impacts on native species whose movement patterns may be impacted. The use of chemosterilants to limit pig reproduction has been explored but is not yet feasible due to continued methodological challenges (Miller et al 1998). Moreover, this technique has the drawback that existing pigs would remain on site for the remainder of their lives. Relocation of pigs to other areas is also not a feasible option due to the risk of spreading disease (Sweitzer and McCann 2007), and because it would likely create a similar pig problem in another area. Methods of frightening or repelling pigs have not been found effective (Barrett and Birmingham 1994).

Options for lethal methods include recreational hunting, poisoning, snaring, and professional hunting including trapping, aerial shooting, team hunting, use of specially trained dogs, and the use of radio-telemetered “Judas” animals. Poisoning and snaring have been used elsewhere but are not considered acceptable in California, due to ethical concerns and risk to non-target species, and we will therefore not discuss these options further. We note that precision shooting can meet standards of euthanasia for wildlife (American Veterinary Medical

Association 2001). Moreover, the earlier an invading population is controlled the more humane the overall management program can be, in that controlling a population while it is still low, prior to its expansion, will minimize the total number of animals that are dispatched.

Recreational (sport) hunting has been the primary means of population control in California (Waithman 1995, Waithman et al. 1999), where feral pigs have been managed as game mammals since 1957 (Mayer and Brisbin 1991). Pigs can be hunted year-round in the state, as long as the hunt occurs on lands that allow hunting and the hunter has the appropriate hunting license and pig tag. Sport hunting has a number of advantages that make it an appealing control method. It is a popular outdoor activity, carcasses are removed from the site, and it can generate revenue via the issuance of pig tags. However, it may be an inadequate tool for pig eradication and even for pig control. Research in Australia and New Zealand suggested that approximately 70% annual removal would be necessary to reduce or maintain numbers at constant levels (summarized in Waithman et al. 1999). Waithman et al. (1999) reviewed hunting records in California and suggested that sport hunting and permitted removals resulted in approximately a 40% reduction in the population each year in the mid 1990s, and that this may have limited populations in some areas but not others. Given that sport hunting of pigs has been a long-standing and popular activity in many areas of California, and that populations have continued to grow despite hunting, suggests that sport hunting alone may not be an effective means of feral pig control.

There are several factors that reduce the effectiveness of recreational hunting. Hunter access to private and public lands differ substantially. While some private and public lands (e.g., Bureau of Land Management, Forest Service) may be hunted heavily, many private lands and some public lands (i.e., state and national parks) prohibit hunting. It is possible that pigs will find refuge on the latter lands. Hunters may also select areas of high pig density rather than low density areas, thereby reducing their effectiveness at controlling or eliminating pigs at low population size. In addition, hunting efficiencies decrease in dense habitats (Coblentz and Baber 1987), making it possible that pigs will seek refuge in dense chaparral habitats, tamarisk (as observed in Imperial County), and *Arundo* (as observed in Riverside County), resulting in reduced hunter take.

While recreational hunting may contribute to control efforts, Barrett and Birmingham (1994) suggest that it is not recommended as a sole means of pig control, and that other more intensive methods are necessary. Professional hunting programs have been implemented in a number of locations to control and remove pigs. Aerial shooting has been used in California (e.g., Morrison et al. 2007), and can be an efficient means of reducing population size. Aerial shooting can also be cost effective, depending on how helicopter support is integrated into the overall management strategy (Morrison 2008). It is important to note that hunting pressure, whether by recreational or professional hunters, can result in pigs learning to avoid detection, such as by becoming more nocturnal or retreating to dense vegetation and/or unhunted areas (Barrett and Birmingham 1994), so it is important to factor this into the planning of the overall management strategy (Morrison et al. 2007; Morrison 2008).

The effectiveness of shooting efforts can be increased with the use of specially trained dogs (Schuyler et al. 2002) and may be especially useful in finding individual pigs when population densities have declined, for example after other methods have been used or are found to be ineffective. They can also be increased by the use of Judas pigs (Wilcox et al. 2004, Morrison et al. 2007). In this case, pigs are captured, collared with radio or GPS collars, and released, and then are used to find other uncollared pigs. This may be most useful towards the end of an eradication effort, when densities are low and the remaining pigs are difficult to find.

Cage traps have been used extensively in pig control and eradication programs, and may be the most effective control method in areas where pig densities are high. Although the timing and location of trapping need to be carefully considered (to increase the probability of animals entering the trap), this method has been highly successful with as many as 14 pigs captured in one trap during one night (Barrett and Birmingham 1994). Sweitzer and McCann (2007) reported that trapping was a primary method used by natural land mangers in California in their efforts to control or eradicate feral pigs. This method will likely exhibit declining success as population densities decline, or during periods of high food availability, so it may have to be combined with other methods such as shooting, possibly with the assistance of dogs or Judas pigs (Morrison et al. 2007, Sweitzer and McCann 2007). Sweitzer and McCann (2007) reported that during their survey of natural lands managers, the most common method of lethal control was a combination of trapping and hunting.

The selection of methods may be influenced by whether the goal is to control or completely eradicate feral pigs from an area. Sweitzer and McCann (2007), in their survey of natural lands managers, determined that while most managers would prefer a complete eradication program, it was determined by many to be infeasible and they therefore focused their efforts on control. Eradication programs may be infeasible due to lack of resources (e.g., financial, personnel, equipment), and the complex logistics of removing large numbers of pigs from extensive wild lands (Waithman et al. 1999, Bengsen et al. 2008). However, long-term costs of the two options should be considered (Morrison 2008). Although eradication programs may initially exceed the cost of control programs, the long-term cost of control options, including costs to natural landscapes and resources (Section 2.4), should be considered. Parkes (1990) suggested that managers may opt for an eradication program over a control program if the eradication option is cheaper in the long term than an ongoing control program, even when complete eradication is not necessary to protect resources.

The decision to implement a control versus an eradication program is also influenced by different mandates and missions among agencies and land managers. Agencies with a mandate to protect natural resources and biodiversity (and promoting non-consumptive use of resources) will typically be more concerned about pig impacts and will likely promote control or eradication programs, while agencies managing lands where hunting is allowed my be less concerned with pig presence.

Finally, population size and distribution are also important considerations, with eradication efforts likely being most efficient before the population expands numerically and geographically. In discussing management program for feral goats, Parkes (1990) suggested four conditions that must be met to achieve eradication:

1. It must be possible to put all animals at risk. Refugia, where animals are protected from removal activities, should not exist within the planned eradication area.

2. There must be no possibility of recolonization. If animals are known to immigrate into the area, permanent eradication will be impossible.
3. Sufficient funding must be available to maintain eradication activities at a scale and intensity that will remove animals faster than they reproduce.
4. Those attempting eradication must believe that it is possible. This will influence the chance of meeting conditions 1 and 3.

We also note that achieving an eradication goal may be frustrated if the population has been subjected to previous control efforts, because animals may have learned to avoid detection (Morrison et al. 2007). A population that is generally naïve to hunting techniques can provide managers with an important strategic advantage in an eradication effort, and lead to significantly improved efficiency and reduced likelihood of failure (Morrison 2008).

6.2. Recommendations for Management in San Diego County

Our general recommendation for management of feral pigs in San Diego County is to initiate an eradication program as soon as possible. There is no question that the presence of feral pigs can have negative impacts on native ecosystems and species, and possibly also on human health and agricultural resources (Section 2), and that this risk will only increase as the pig population increases. However, an eradication program would have to be preceded by careful planning, coordination, and securing of funds to meet the four conditions listed by Parkes (1990). For example, pigs in San Diego County range on some lands that could serve as refugia from eradication activities, thereby not meeting condition #1. Pig hunting is currently prohibited on San Diego City lands near the El Capitan Reservoir. Hunting is likely also prohibited on some private lands, and access to Tribal lands is restricted. Advance coordination, planning, and temporary arrangements to allow removal activities on these lands would be necessary. Because pigs in San Diego County are known to use a mix of public and private lands an effective and comprehensive coordination program will be critical, and a first step should be to determine if condition #1 (Parkes 1990) can be met collaboratively.

A collaborative approach will also increase the program's chances of meeting condition #2. In these times of limited resources, a collaborative approach may provide some benefits in terms of costs, if agencies can pool their resources and staff to increase efficiencies. It is currently not known how fast the pig population is growing, so it is not known how rapidly animals would have to be removed (in order to exceed the rate of replacement). Although a multi-year field study could be implemented to determine the rate at which the population can replace its losses, this may reduce the probability of a successful eradication program because the population would be able to expand geographically and numerically in the interim, making eradication even more difficult. An option is to estimate the necessary removal rate based on existing published information on growth rates of feral pig populations, and to start an annual abundance survey of the pigs as soon as feasible, to track whether numbers are declining during the first years of the eradication program. The exact survey methods would have to be determined, but could be based on methods to estimate an index of abundance rather than absolute abundance.

Success of an eradication program will also depend on reducing the chances of recolonization (condition #2; Parkes 1990). The probability of natural recolonization from other populations is very small, given that the nearest known population is nearly 120 km (roughly twice the known maximum dispersal distance; Lapidge et al. 2004) from the current San Diego population (Figure 3). The risk of human-mediated re-colonization, whether by purposeful or accidental means, is likely much greater but difficult to quantify. A public awareness program to inform the public, including private landowners in the region, of the negative impacts of feral pig populations might help reduce this probability. Establishment of County regulations prohibiting release of pigs could also decrease this risk. A public awareness program would also increase general support for an eradication program, and would be most effective if presented in a collaborative (multi-partner) manner.

If, after initial assessments, it is believed that the first three conditions in Parkes (1990) can not be met, a control program should be initiated. The costs and logistics of control and eradication efforts will increase as the population grows and expands to currently un-occupied habitats. Although eradication programs have been considered infeasible in some locations (e.g., Barrett and Birmingham 1994), the opportunity to clear San Diego County of feral pigs may still be very feasible. Implementing an eradication effort now while the population appears to be focused near the El Capitan Reservoir will have a higher probability of success and lower long-term costs than if efforts are delayed. Observations suggest that the pigs may focus their activities near the reservoir and other nearby water sources in the hot summer months. It is likely that an intensive trapping operation initiated during a period of aggregation and low food supplies, followed by removal of remaining animals via professional shooting, possibly with the aide of dogs or Judas pigs, would provide the most effective solution.

When evaluating the estimated costs of an eradication program, land managers are encouraged to consider the long-term costs of pig damage and control if they are not removed in the near future. Pig removal should be seen as protecting existing investments, because failure to control or eradicate pigs will threaten existing protected lands, including the unique ecosystems and species of this region. As such, investments made today to protect these resources will translate to future monetary savings.

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Appendix A: Individuals Interviewed and/or Contacted For Input

Agency or Organization	Name
(no affilitation)	Cindy Buxton
(no affiliation)	Nathan Weflen
California Department of Fish and Game	Randy Botta
California Department of Fish and Game	Channelle Davis
California Department of Fish and Game, retired	Jim Davis
California Department of Fish and Game	Rick Fischer
California Department of Fish and Game	Gerry Mulcahy
California Department of Fish and Game	Doug Updike
California State Parks	Jim Dice
California State Parks	Gary Reece
Cibola National Wildlife Refuge	Mike Oldham
Orange County Water District	Dick Zembal
San Diego City	Gary Norris
San Diego City	Joe Webber
San Diego County	Tom Oberbauer
San Diego County	Ralph Steinhoff
San Diego Water Department	Jeff Pasek
Terra Peninsular	Jesús Zatarain
The Nature Conservancy	Scott Morrison
U.S. Forest Service	Joan Friedlander
U.S. Forest Service	Jell Wells
U.S. Forest Service	Kirsten Winter
U.S. Forest Service, retired	Rich Hawkins
Universidad Autónoma de Baja California	Jorge Alaniz
Universidad Autónoma de Baja California	Ricardo Eaton
Universidad Autónoma de Baja California	Roberto Martinez Gallardo
University of California Cooperative Extension, Santa Barbara	Bill Tietje
University of California, Davis, Agricultural Issues Center	Marcia Kreith
University of California, Berkeley	Reginald Barrett
University of California, Berkeley	Rick Sweitzer
University of California, Davis	Dirk Van Vuren
USDA Wildlife Services	John Turman
Viejas Tribal Government	Lisa Haws

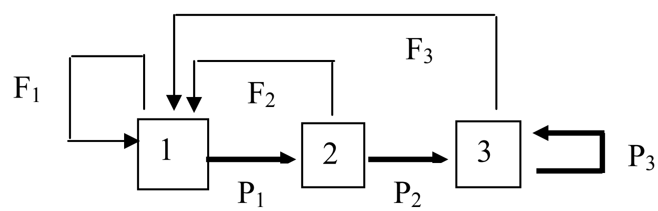
Appendix B: Methods Used for Modeling Population and Range Expansion

We modeled the expansion of the San Diego County pig population to examine their potential numeric and geographic expansion during a 10-20 year period. Our intent was to generate and examine scenarios of how this population may grow in the near future, and to identify those geographic areas where one might be most likely to find pigs as the population grows.

We intentionally kept our modeling approaches simple because we did not have adequate information specific to pigs in this area to develop complex models. We based our models on published information and expert opinion. Our general approach was to generate population estimates for 10 and 20 years from the time of release, and to identify suitable habitat in our study area. We subsequently compared these model results in the context of known pig spatial use patterns (e.g., density and dispersal distances) to evaluate how much and what portions of the landscape the expanded population might potentially use.

Modeling Population Growth

We modeled population growth with a Leslie matrix model (Leslie 1945, 1948), following the approach used by Bieber and Ruf (2005). In this model, which models only females, pigs are assumed to progress through 3 age classes as shown in the three boxes in the diagram below. Following Bieber and Ruf, we used a 3-age class model because fecundity and survival rates have been reported to differ among age classes.



In this model, age-class 1 includes juveniles (0-1 yr), age-class 2 includes yearlings (>1 and ≤ 2 yrs), and age-class 3 includes adults (>2 years). P_1, P_2, and P_3 represent age-specific survival rates, and F_1, F_2, and F_3 represent age-specific fertility rates. We assumed that animals less than one year of age could reproduce, an assumption that is supported by observations of early (< 1 year) maturation and reproduction of pigs in California (Barrett 1978). We also assumed an equal sex-ratio, which is supported by observations in Texas (Ilse and Hellgren 1995, Adkins and Harveson 2007) and, at least during some years, in California (Sweitzer et al. 2000). Animals > 2 years old were able to remain in the third age-class with a survival rate of P_3. The model assumes a post-breeding census, and that females typically produce 1 litter per year (Taylor et al. 1998).

Thus, the projection matrix for the model was:

$$A = \begin{bmatrix} F_1 & F_2 & F_3 \\ P_1 & 0 & 0 \\ 0 & P_2 & P_3 \end{bmatrix} \quad \text{and } N = \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix}$$

The population projection matrix, A, includes the vital rates shown in the above life-cycle figure, and N is a vector representing the age-structured population. The size and structure of the population between times t and t+1 can be computed with the equation:

$$N_{t+1} = A*N_t$$

By multiplying A and N repeatedly, one can calculate population size at specific time periods.

We used published data on reproduction and survival rates to parameterize our model. Bieber and Ruf (2005) presented published vital rates for feral pigs under poor, intermediate, and good environmental conditions, but because most of these rates were from studies of feral pigs in Europe, we modified some rates, based on published literature, to better represent pig populations in California (Table B-1). Following Bieber and Ruf, we defined fertility as F = (survival)*(proportion females reproducing)*(0.5*litter size), with the last part of the equation accounting for the fact that the model is for females only, and that it assumes an equal sex ratio.

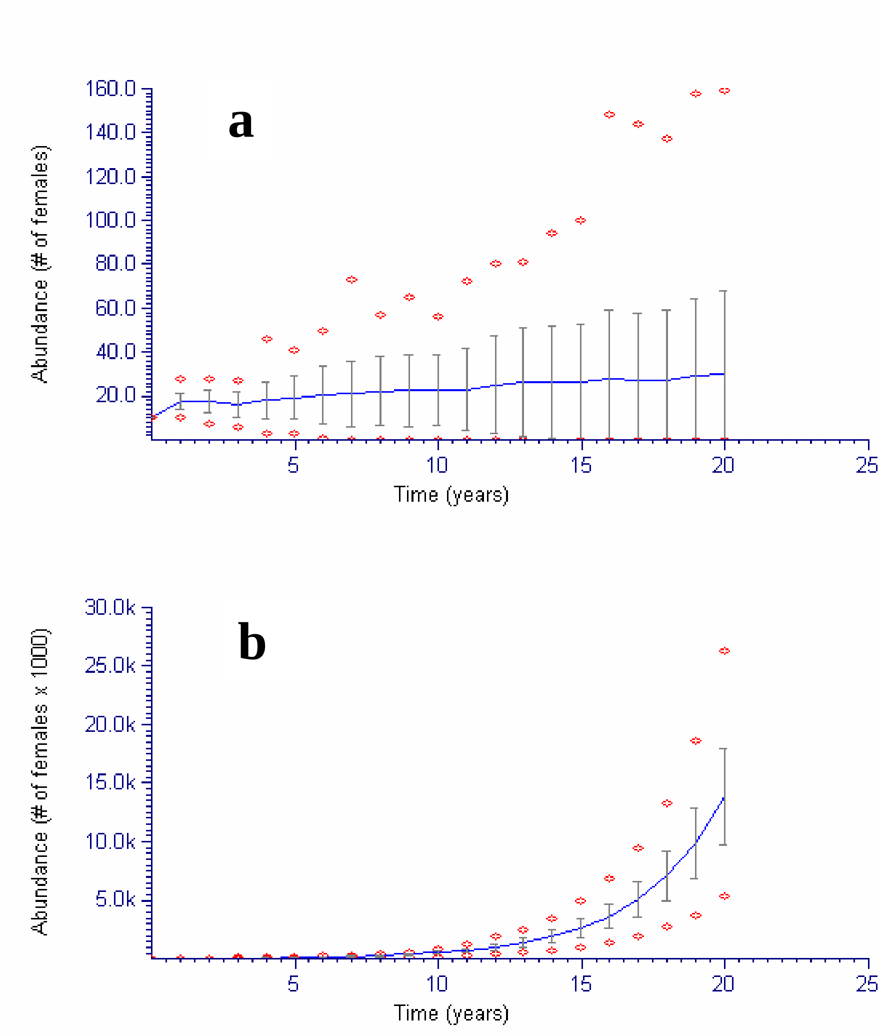
Table B-1. Mean litter size, proportion of females in each age class reproducing, yearly survival, and fertilities used in the matrix model. Values were based on Bieber and Ruf (2005) unless otherwise indicated.

Environmental Conditions	Age Class	Mean Litter Size	Proportion of Females Producing	Survival Rate (P)	Fertility Rate (F)
Poor					
	Juvenile	4.1[a]	0.30	0.25	0.154
	Yearling	3.5[a]	0.65[b]	0.68[d]	0.774
	Adult	5.9[a]	0.70[c]	0.68[d]	1.404
Intermediate					
	Juvenile	4.8[a]	0.40	0.33	0.317
	Yearling	4.4[a]	0.70[b]	0.86[d]	1.324
	Adult	6.3[a]	0.75[c]	0.86[d]	2.032

[a] From Taylor et al. 1998. We used their observed mean as our intermediate level and their mean minus one standard deviation as our poor level. Values were in the range observed in California (Sweitzer et al. 2000).
[b] Estimated from number of adults pregnant or lactating during two years (Sweitzer et al. 2000), with the assumption that the proportion of yearlings reproducing will be lower than the proportion of adults reproducing.
[c] Estimated from number of adults pregnant or lactating during two years (Sweitzer et al. 2000).
[d] Increased from values used by Bieber and Ruf (2005) to better represent a population with lower hunting pressure. For adults, we used the mean observed by Adkins and Harveson (2007) as our intermediate level, and the lower end of their 95% confidence interval for poor conditions. We assumed that yearlings would have similar survival as adults (Focardi et al. 2008).

We incorporated demographic stochasticity by allowing survivors to be sampled from a binomial distribution, and the number of young from a Poisson distribution, and simulated each model run 50 times for a duration of 20 years. We did not incorporate density dependence in this analysis.

We began the simulation with a total of 10 females (8 adults, 1 yearling, and 1 juvenile), to approximately simulate a release of 20 animals (assuming an equal sex ratio). The following graphs present model simulation results under a) poor and b) intermediate environmental conditions, with the blue line indicating mean simulation result with +/- 1 standard deviation, and red circles indicating minimum and maximum simulation results.



Simulation results indicated population growth, albeit at a slow rate, under low environmental conditions, and rapid growth at intermediate conditions. See Section 4.1 for additional discussion of results.

Modeling Potential Range Expansion

We defined our study area as lands within 120 km of the current known distribution of pigs in San Diego. This distance is approximately double the maximum dispersal distance reported for pigs (Lapidge et al. 2004) and it also allows the study area to include all of San Diego County and the U.S. Peninsular Ranges (Figure 2). We developed a habitat model for pigs in California based on the California Wildlife Habitat Relationship values (CWHR; CDFG 2008). Although a habitat model for feral pigs had recently been developed by Loggins (2007), that model did not include areas south of the Mexican border, and would therefore not represent our entire study area. Habitat suitability ratings in the CWHR system are based on a species' specific habitat needs in relation to reproduction, cover, and food, and reflect that feral pigs prefer areas with heavy cover and abundant forage (CDFG 2008). Ratings range from 0 to 1.0, with areas rated as 1.0 representing the best habitat (and areas rated as 0 considered to be unsuitable). In California, pigs are most often associated with oak woodlands, but are also found in a variety of other vegetation communities, such as riparian areas, meadows, pastures, irrigated farmlands, and dense shrublands, such as chaparral (Barret and Birmingham 1994). We modified CWHR ratings for feral pigs, based on expert opinion, by making the following adjustments to ratings:

- For all habitat types rated >0, we increased the rating by 25% if habitat was within 900 m of surface water, and by 10% if habitat was between 900 and 1800 m from surface water (Figure B-3). This reflected that the distribution of feral pigs is often associated with water (Barrett 1982). We assumed that water would be a particularly important habitat attribute in the relatively warm and arid southern California climate. Distances were selected based on published home ranges for feral pigs in California, which had an overall mean of approximately 2.5 km^2 (Sweitzer et al. 2000). A home range of 2.5 km^2 has a radius and diameter of approximately 900 and 1800 m, respectively.
- For grassland and selected agricultural lands, we increased the rating by 25% if habitat was within 900 m of surface cover, defined here as any tree-dominated or chaparral habitat types in the CWHR, and by 10% if habitat was between 900 and 1800 m from cover. This reflected that pigs often use grassland and selected agricultural lands but that the level of use may be related to proximity to cover. Distances were based on home ranges of pigs in California, as described above. Rating increases due to proximity to cover were applied to the following CWHR habitat types: annual grasslands, perennial grasslands, wet meadow, pasture, dryland and irrigated grain crops, irrigated hayfields, irrigated row and field crops, deciduous orchard, evergreen orchard, and vineyards.

For identifying CWHR classifications and modeling habitat suitability, we used multiple GIS layers available for our study area (Table B-2). We used the FVeg and 2000IF datalayers as our primary vegetation layers for the U.S. and Mexico portions of our study, respectively (Figures B-1 and B-2). To further differentiate agricultural lands in the U.S. we replaced all lands classified by FVeg as agriculture with SCAG classifications for areas outside of San Diego County, and with San Diego 1995 classifications for areas within San Diego County, because these layers had higher resolution for agricultural lands than FVeg. For areas within Mexico, we retained the IF2000 agricultural assignments. We cross-walked all the above classifications to CWHR habitat classes (Table B-3). Although data existed to further differentiate urban lands in the U.S., similar data did not exist for Mexico, so we retained a single classification for urban.

After lands in our study area were assigned a suitability rating according to our modifications of the CWHR, we examined the potential ability of feral pigs to disperse across the study area. We identified lands contiguous with the current known distribution of pigs in San Diego County that had ratings ≥ 0.75, representing the most suitable habitat in our study area, and considered this the currently occupied "patch" of habitat (Figure 5). We examined potential habitat dispersal by identifying other patches of habitat with ratings ≥ 0.75 that were within two selected dispersal distances. We selected the distance of 4.5 km as a conservative (likely) dispersal distance based on observations that female pigs in Sweden were documented to disperse an average of 4.5 km from their natal sites (males dispersed an average of 16.6 km; Truve and Lemel 2003). We selected 15 km as a less conservative (lower probability) dispersal distance. Although male pigs in Sweden were documented to disperse an average of 16.6 km from their natal sites, some of this movement may have been across high quality habitat. In addition, genetic analyses indicated that pig populations separated by 25 km were not commonly connected via migration (Hampton et al. 2004). Thus, we assumed 15 km as a maximum migration distance across habitat with low suitability. In our analyses, we assumed that pigs could cross roads and any habitat with a non-zero suitability rating, but that they could not cross urban areas or the international border fence (Figures 6 and 7).

After identifying patches of habitat with ratings ≥ 0.75 within the above dispersal distances, we estimated the number of pigs that these areas could potentially support, by using published density values for pigs in California and other southwestern states. We used a range of 0.7 – 3.8 pigs/km^2 based on densities observed in central and northern California (Sweitzer et al. 2000). The lower limit of this range is similar to densities observed in the arid Chihuahuan Desert in Texas (0.65 pigs/km^2; Adkins and Harveson 2007), suggesting that potentially lower densities in the relatively arid portions of our study area could fall within this range.

Table B-2. Data sources used for analyses in this report.

Data	Source	Type	Scale	Date
Vegetation: California	1. FRAP Multi source landcover data v. 02_2 (Fveg 02_2g.2002), http://frap.fire.ca.gov/data/frapgisdata/select.asp	Raster	100 m	2002
Vegetation: Mexico	1. Inventario Forestal Nacional 2000-2001, http://132.248.14.16/inventario.html	Raster	15 m	2000
Land use: California	1. SCAG, http://www.scag.ca.gov/planning.htm 2. SANDAG 1995 Vegetation, http://www.sandag.org/resources/maps_and_gis/gis_downloads/senlu.asp	Vector Vector	1:24,000 1:24,000	2005 1995
Land use: Mexico	1. Inventario Forestal Nacional 2000-2001, http://132.248.14.16/inventario.html	Raster	15 m	2000
Hydrology: California	1. NHD, http://nhd.usgs.gov/ 2. ESRI® Data & Maps, http://www.esri.com	Vector Vector	1:100,000 1:200,000	2005 2002
Hydrology: Mexico	1. ESRI® Data & Maps, http://www.esri.com	Vector	1:200,000	2002
Watersheds: California	1. CALWATER 2.2, http://gis.ca.gov/meta.epl?oid=22175	Vector	1:24,000	1999
Watersheds: Mexico	1. Delineated from SRTM, http://www2.jpl.nasa.gov/srtm	Raster	90m	2006
Ownership: California	1. Public Conservation and Trust Lands, PCTL_05, http://gis.ca.gov/catalog/BrowseRecord.epl?id=31122 2. San Diego Parcel Data, http://www.sangis.org/	Vector Vector	1:100,000 1:24,000	2007 2009
Ownership: Mexico	1. The Nature Conservancy	Vector	1:100,000	various
Federal Management Categories	1. BLM's, http://www.blm.gov/ca/gis/ 2. USFS, http://www.fs.fed.us/r5/rsl/clearinghouse/gis-download.shtml	Vector Vector	Various 1:100,000	various various
State Management Categories	1. California Department of Fish and Game, http://www/dfg/ca/gov/biogeodata/gis/clearinghouse.asp	Vector	1:24,000	2008
Roads – California	1. TIGER, http://www.esri.com/data/download/census2000_tigerline/index.html 2. ESRI® Data & Maps, http://www.esri.com	Vector Vector	1:100,000 1:200,000	2000 2002
Roads – Mexico	1. ESRI® Data & Maps, http://www.esri.com	Vector	1:200,000	2002
GAP ratings – California	1. The California Gap Analysis Project (GAP), http://www.biogeog.ucsb.edu/projects/gap/gap_home.html	Vector	1:100,000	1999
International border fence	1. The Nature Conservancy	Vector	1:100,000	2009

Table B-3. Crosswalks between selected vegetation and agricultural classification systems and CWHR classes.

Selected Vegetation/Land Use Categories	**Corresponding CWHR Rating**
San Diego 95 Agriculture Classes	
Extensive Agriculture - Field/Pasture Row Crops	Irrigated Hayfied or Irrigated Row and Field Crops
Field/Pasture	Pasture or Irrigated Hayfield
General Agriculture	Dryland Grain Crops or Irrigated Grain Crops
Intensive Agriculture – Dairies, Nurseries, Chickens	Urban
Orchards and Vineyards	Deciduous Orchard, Evergreen Orchard, or Vineyard
Row Crops	Irrigated Row and Field Crops
SCAG Agriculture Classes	
Orchards and vineyards (active and abandoned)	Deciduous Orchard, Evergreen Orchard, or Vineyard
Irrigated cropland and improved pasture land	Irrigated Grain Crops, Irrigated Hayfield, or Irrigated Row and Field Crops
Non-irrigated cropland and improved pasture land	Dryland grain crops or Pasture
Horse ranches	Pasture
Dairy, intensive livestock, and associated facilities	Urban
Nurseries	Urban
Other agriculture	Urban
Packing houses and grain elevators	Urban
Poultry operations	Urban
IF 2000 Classes	
Agricultura De Humedad	Irrigated Grain Crops, Irrigated Hay field, or Irrigated Row and Field Crops
Agricultura De Riego (Incluye Riego Eventual)	Irrigated Grain Crops, Irrigated Hay field, or Irrigated Row and Field Crops
Agricultura De Temporal Con Cultivos Anuales	Dryland grain crops
Agricultura De Temporal Con Cultivos Permanentes Y Semipermanentes	Evergreen orchard, Deciduous orchard, or Vineyard
Area Sin Vegetacion Aparente	Barren
Asentamiento Humano	Urban
Bosque De Encino	Montane Hardwood, Blue Oak Woodlands, Valley Oak Woodland, Coastal Oak Woodland, or Blue Oak-Foothil Pine
Bosque De Encino Con Vegetacion Secundaria Arbustiva Y Herbacea	Montane Hardwood, Blue Oak Woodlands, Valley Oak Woodland, Coastal Oak Woodland, Blue Oak-Foothil Pine, or Mixed Chaparral
Bosque De Pino	Lodgepole Pine, Sierran Mixed Conifer, Jeffrey Pine, Ponderosa Pine, or Eastside Pine
Bosque De Pino Con Vegetacion Primaria Y	Lodgepole Pine, Sierran Mixed Conifer, Jeffrey Pine,

Secundaria Arborea	Ponderosa Pine, Eastside Pine, Montane Hardwood Conifer, or Blue Oak-Foothill Pine
Bosque De Pino Con Vegetacion Secundaria Arbustiva Y Herbacea	Lodgepole Pine, Sierran Mixed Conifer, Jeffrey Pine, Ponderosa Pine, Eastside Pine, Montane Hardwood Conifer, or Blue Oak-Foothill Pine
Bosque De Pino-Encino (Incluye Encino-Pino)	Montane Hardwood-Conifer, Blue-Oak-Foothill Pine
Bosque De Pino-Encino (Incluye Encino-Pino) Con Vegetacion Secundaria	Montane Hardwood-Conifer, Blue-Oak-Foothill Pine
Bosque De Tascate	Mixed Chaparral, Montane Chaparral, Chamise-Redshank Chaparral, Juniper, Subalpine Conifer, Red Fir, Sierran Mixed Conifer, White Fir, Klamath Mixed Conifer, Douglas Fir, or Closed-Cone Pine-Cypress
Bosque De Tascate Con Vegetacion Secundaria Arbustiva Y Herbacea	Mixed Chaparral, Montane Chaparral, Chamise-Redshank Chaparral, Juniper, Subalpine Conifer, Red Fir, Sierran Mixed Conifer, White Fir, Klamath Mixed Conifer, Douglas Fir, or Closed-Cone Pine-Cypress
Chaparral	Montane Chaparral, Mixed Chaparral, or Chamise-Redshank Chaparral
Chaparral Con Vegetacion Secundaria	Montane Chaparral, Mixed Chaparral, or Chamise-Redshank Chaparral
Cuerpo De Agua	Water
Matorral Desertico Microfilo	Desert Scrub
Matorral Desertico Microfilo Con Vegetacion Secundaria	Desert Scrub
Matorral Desertico Rosetofilo	Desert Succulent Scrub
Matorral Rosetofilo Costero	Coastal Scrub
Matorral Rosetofilo Costero Con Vegetacion Secundaria	Coastal Scrub
Pastizal Inducido	Pasture
Pastizal Natural (Incluye Pastizal-Huizachal)	Annual Grassland or Perennial Grassland
Popal-Tular	Fresh Emergent Wetland
Riego Suspendido	Dryland Grain Crops or Barren
Vegetacion De Desiertos Arenosos	Desert Scrub or Barren
Vegetacion De Dunas Costeras	Barren
Vegetacion De Galeria (Incluye Bosque, Selva Y Vegetacion De Galeria)	Montane Riparian or Valley Foothill Riparian
Vegetacion Halofila Y Gipsofila	Alkali Desert Scrub

Figure 1. Distribution of feral pigs in California in 1997, based on available occurrence data and professional knowledge (CDFG 2008), and by county during 2004-2006, based on wild pig tag returns or depredation permits issued in each county (Sweitzer and McCann 2007).

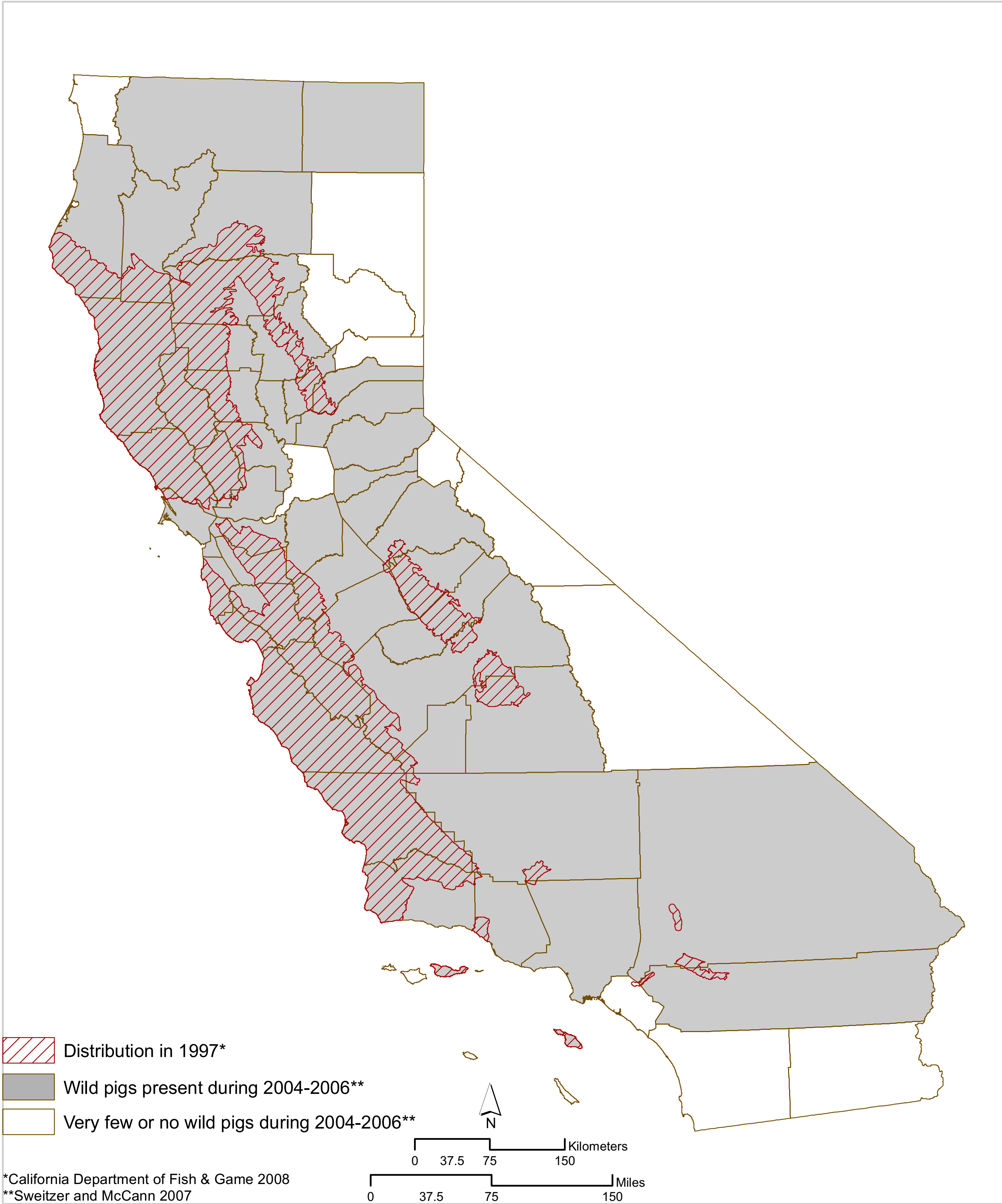


Figure 2. Project study area in southern California.

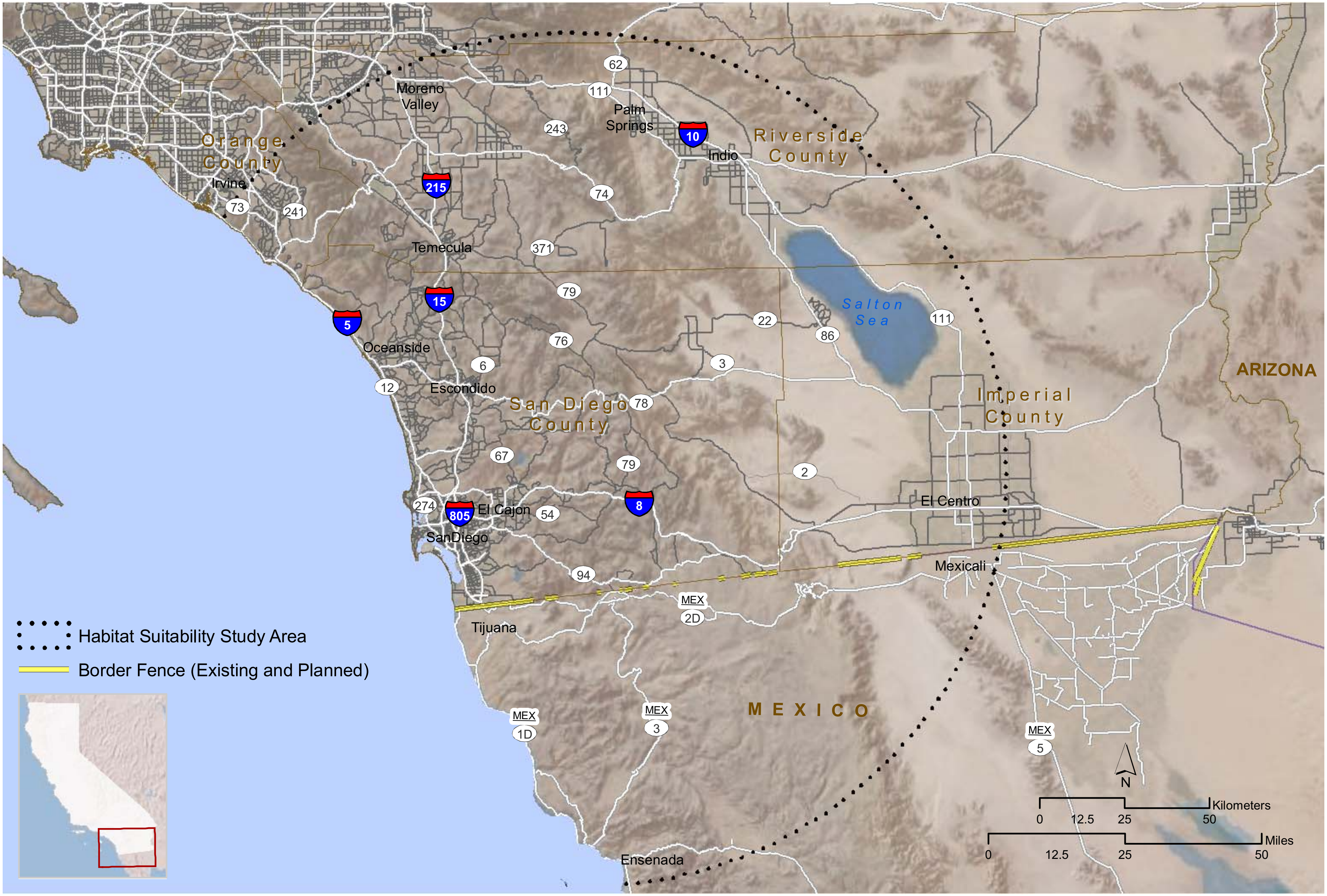


Figure 3. Known populations of feral pigs in southern California (San Diego, Imperial, Riverside, and Orange counties)

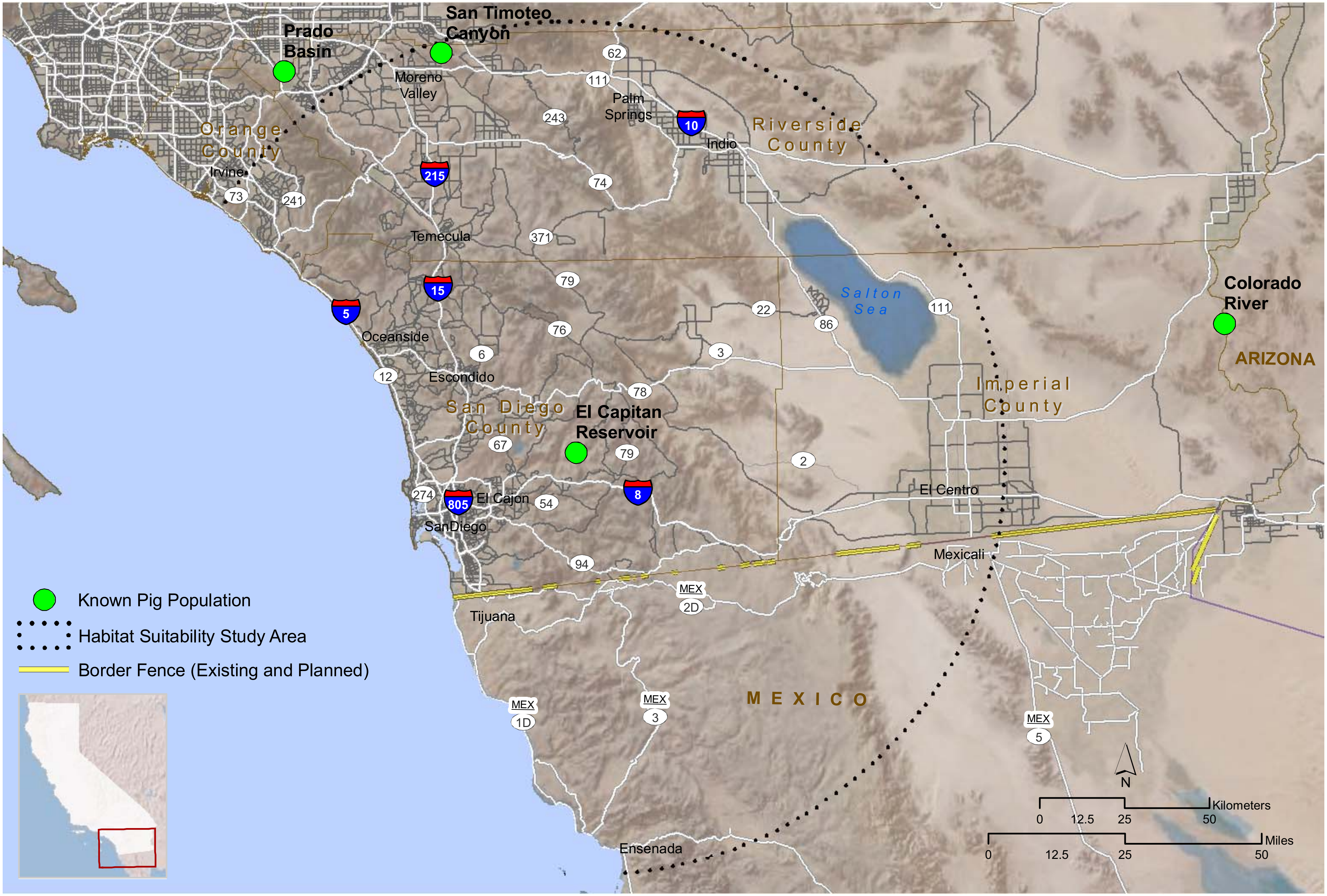
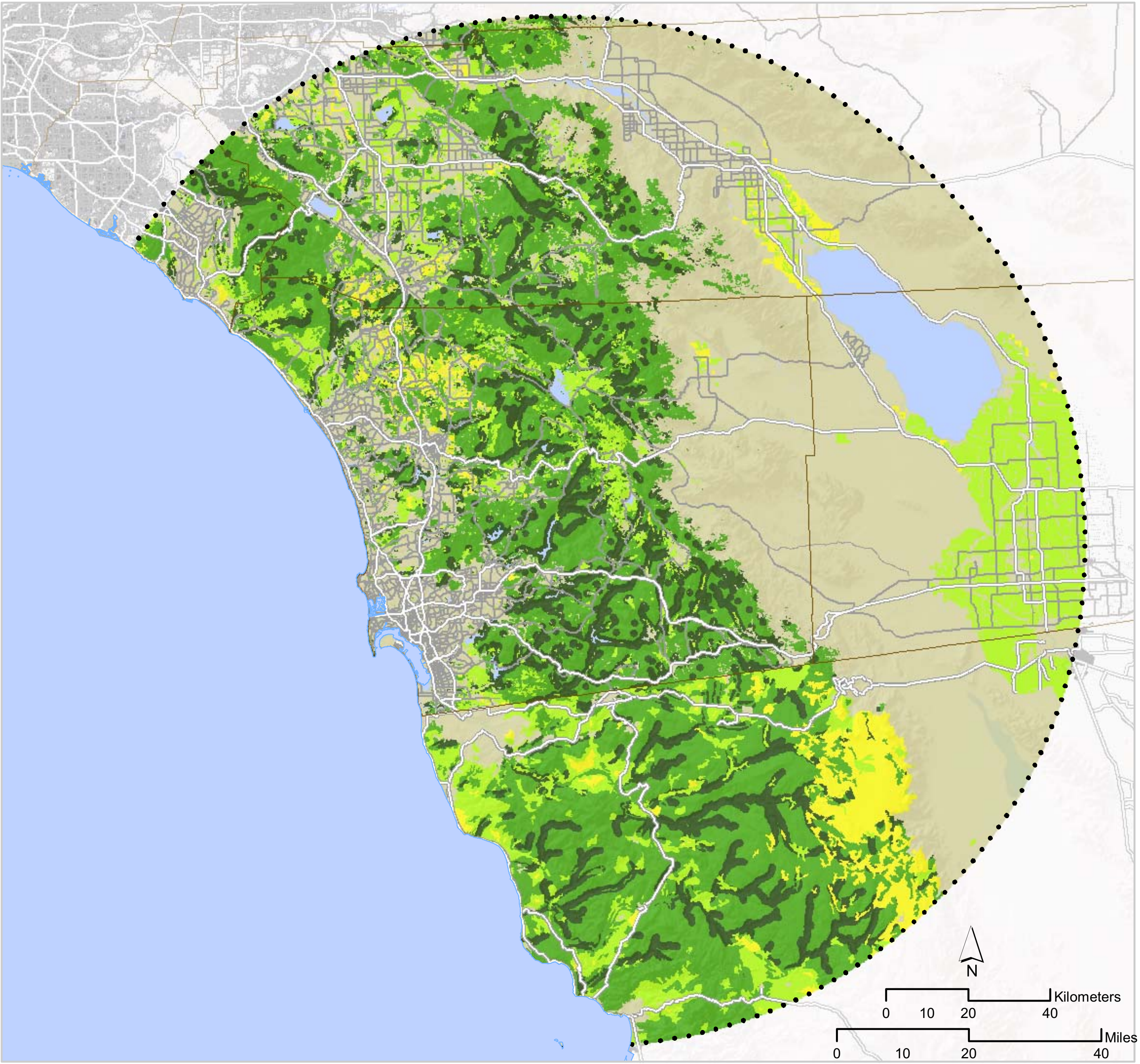


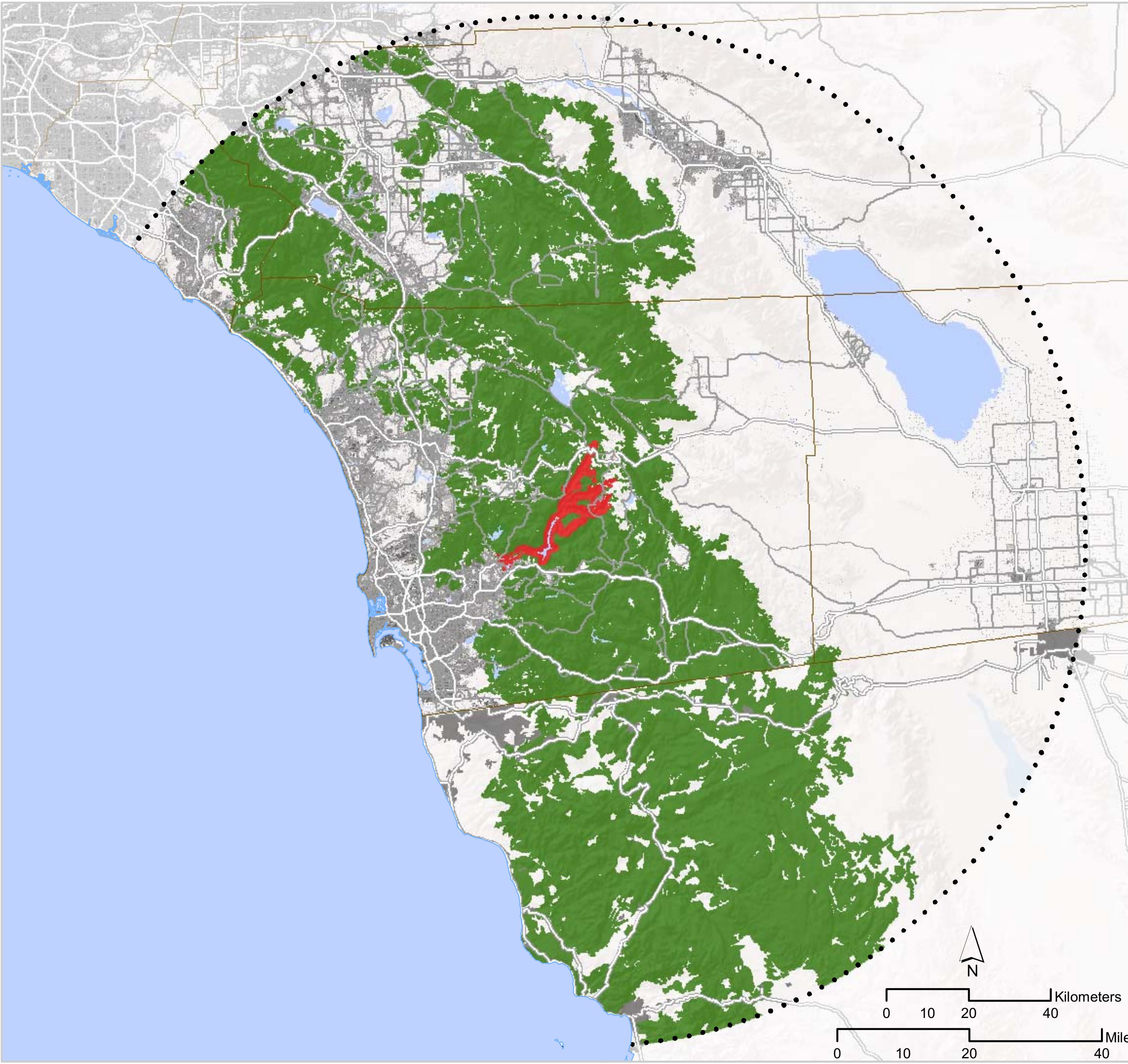
Figure 4. Pig habitat suitability categories within the habitat suitability study area.



Numeric Rating

- 0
- 0.001 - 0.249
- 0.250 - 0.499
- 0.500 - 0.749
- ≥ 0.750

Figure 5. Medium to high suitability habitat contiguous with current distribution of pigs in San Diego County



Contiguous habitat rated as ≥ 0.75

Contiguous habitat rated as ≥ 0.50

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Figure 6. Habitat with suitability ≥0.75, within 4.5 km dispersal distance of currently occupied patch, using a stepping stone dispersal process

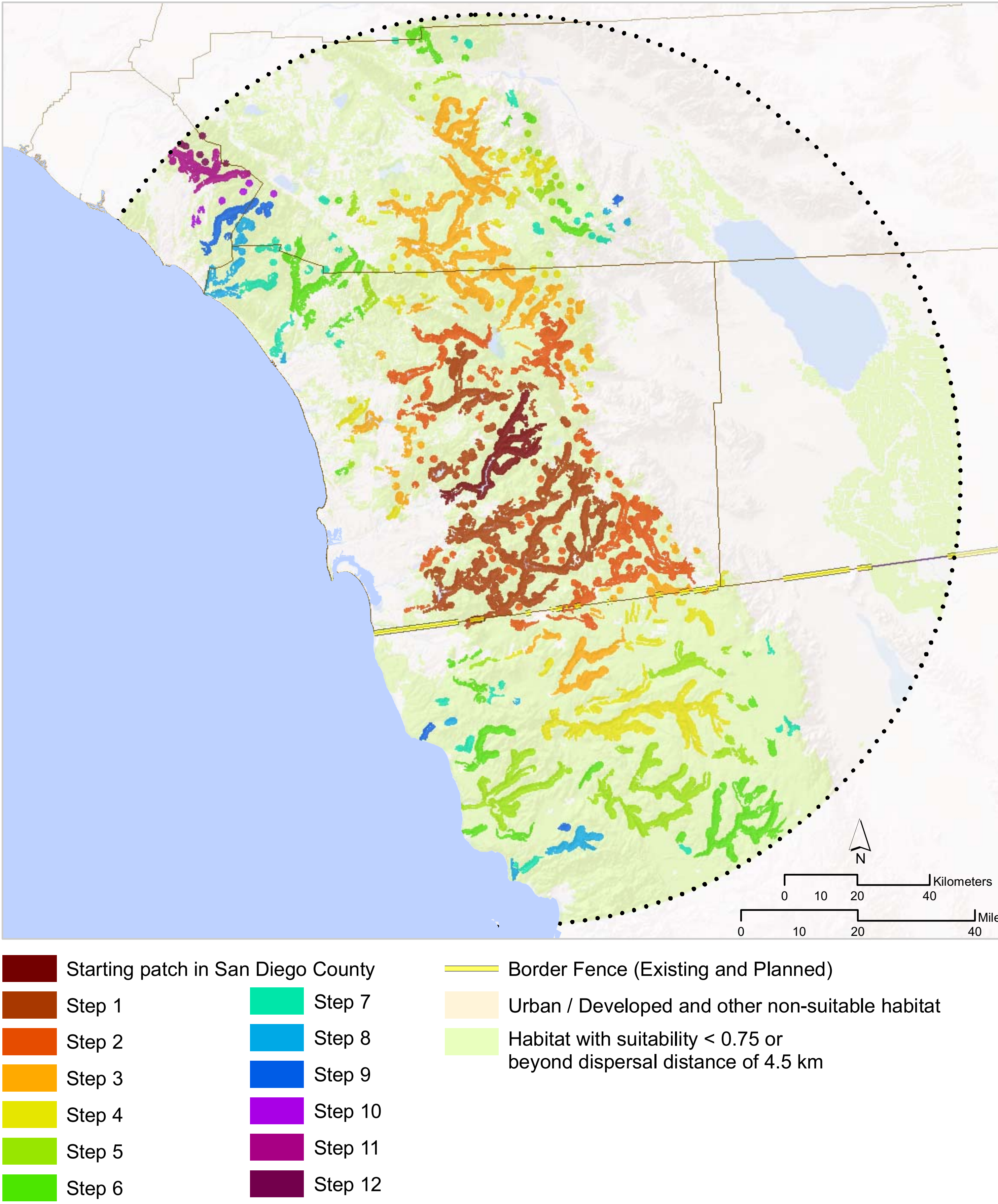

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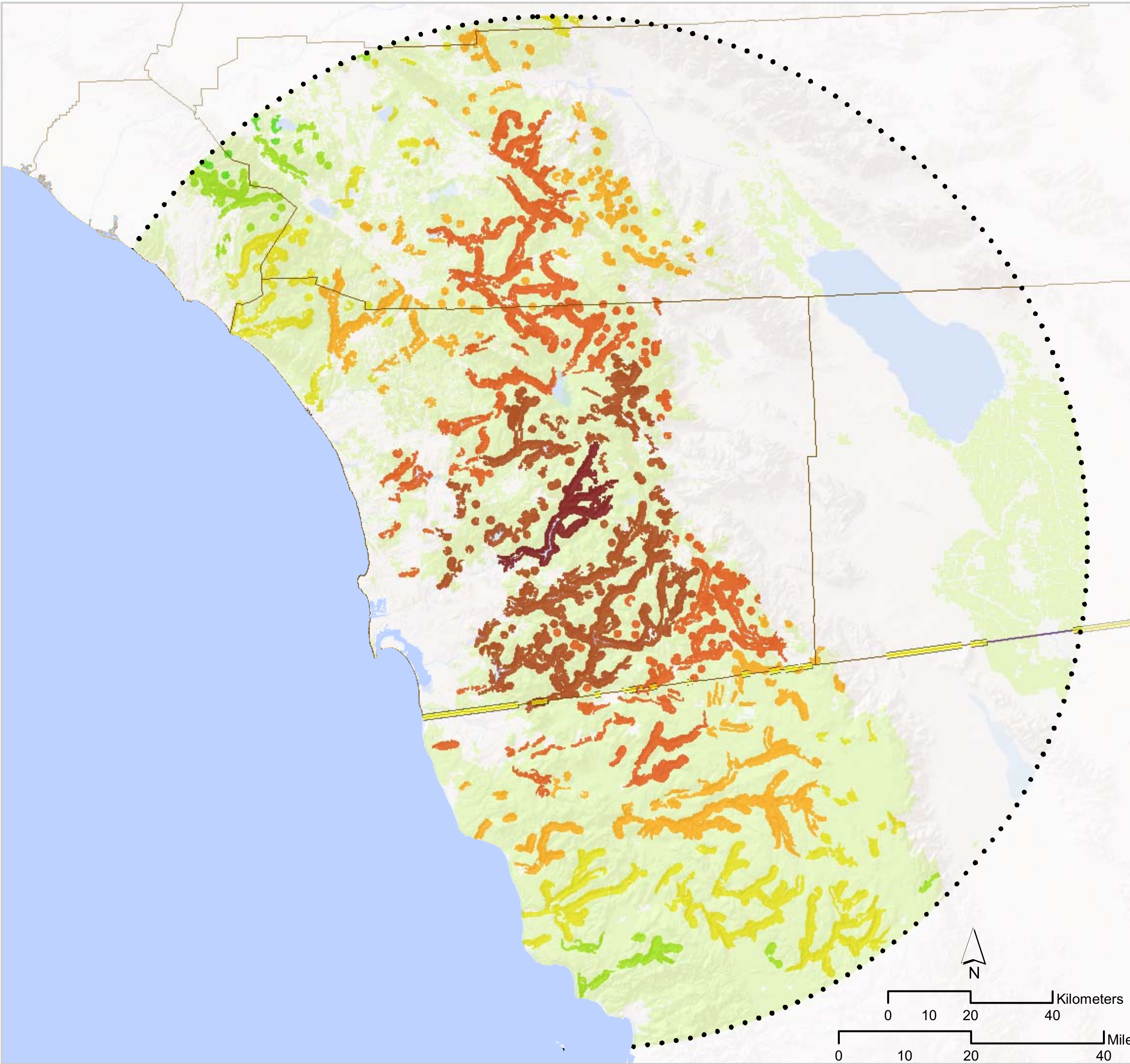
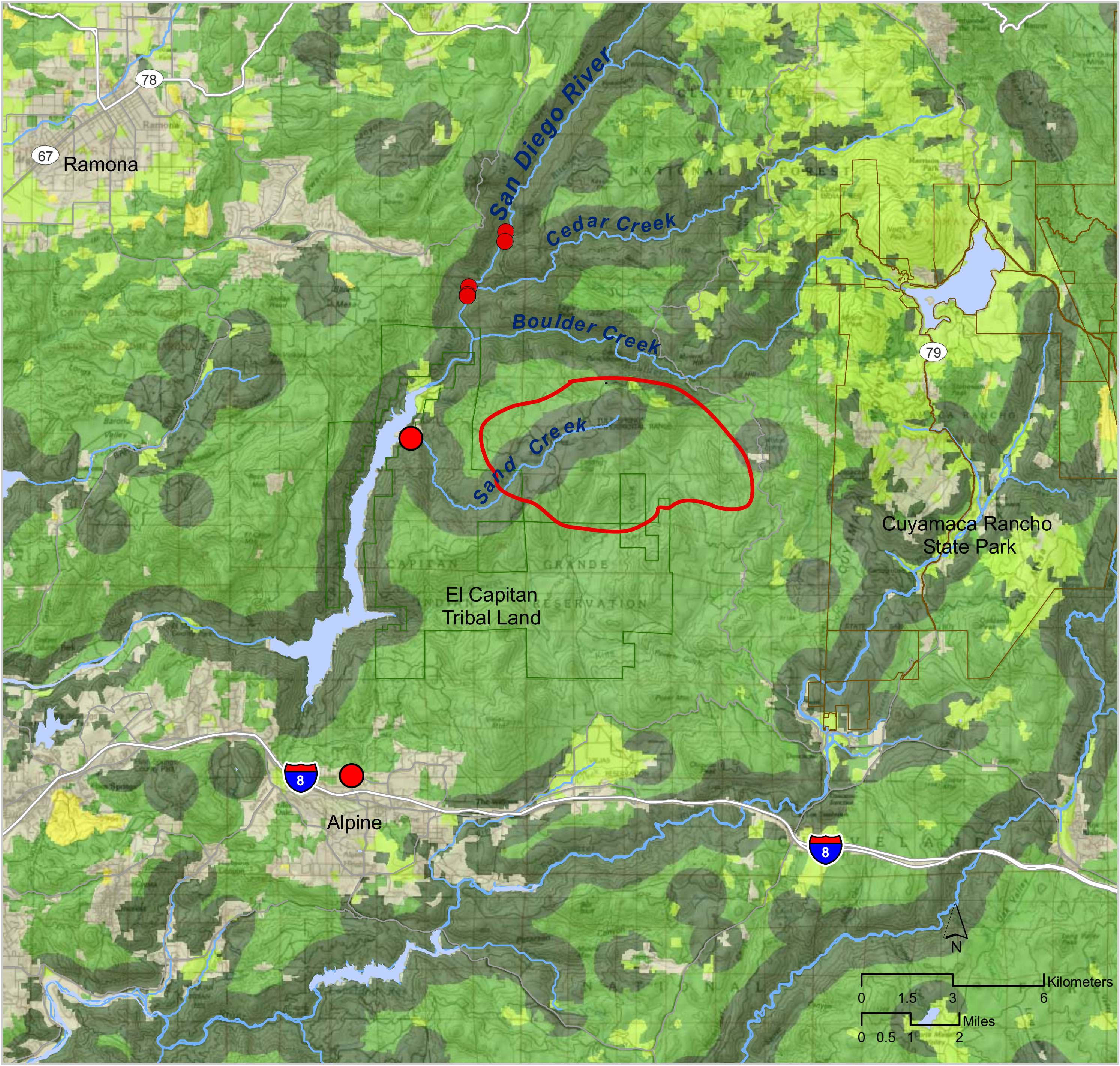
Figure 7. Habitat with suitability ≥0.75, within 15 km dispersal distance of currently occupied patch, using a stepping stone dispersal process



- Starting patch in San Diego County
- Step 1
- Step 2
- Step 3
- Step 4
- Step 5
- Step 6
- Border Fence (Existing and Planned)
- Urban / Developed and other non-suitable habitat
- Habitat with suitability < 0.75 or beyond dispersal distance of 4.5 km

Figure 8. Reported observations of feral pigs or pig sign in San Diego County



Feral Pig Habitat Suitability

Numeric Rating

- 0
- 0.001 - 0.249
- 0.250 - 0.499
- 0.500 - 0.749
- ≥ 0.750

Reported observations of feral pigs or pig sign

Area of reported observations of feral pigs

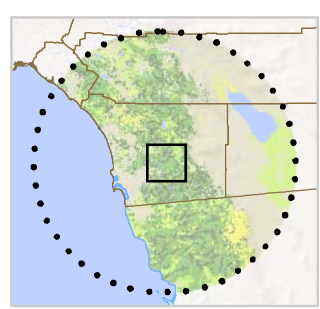


Figure 9. Land ownership within the U.S. portion of the habitat suitability study area. (ownership data were not available for the majority of lands in México)

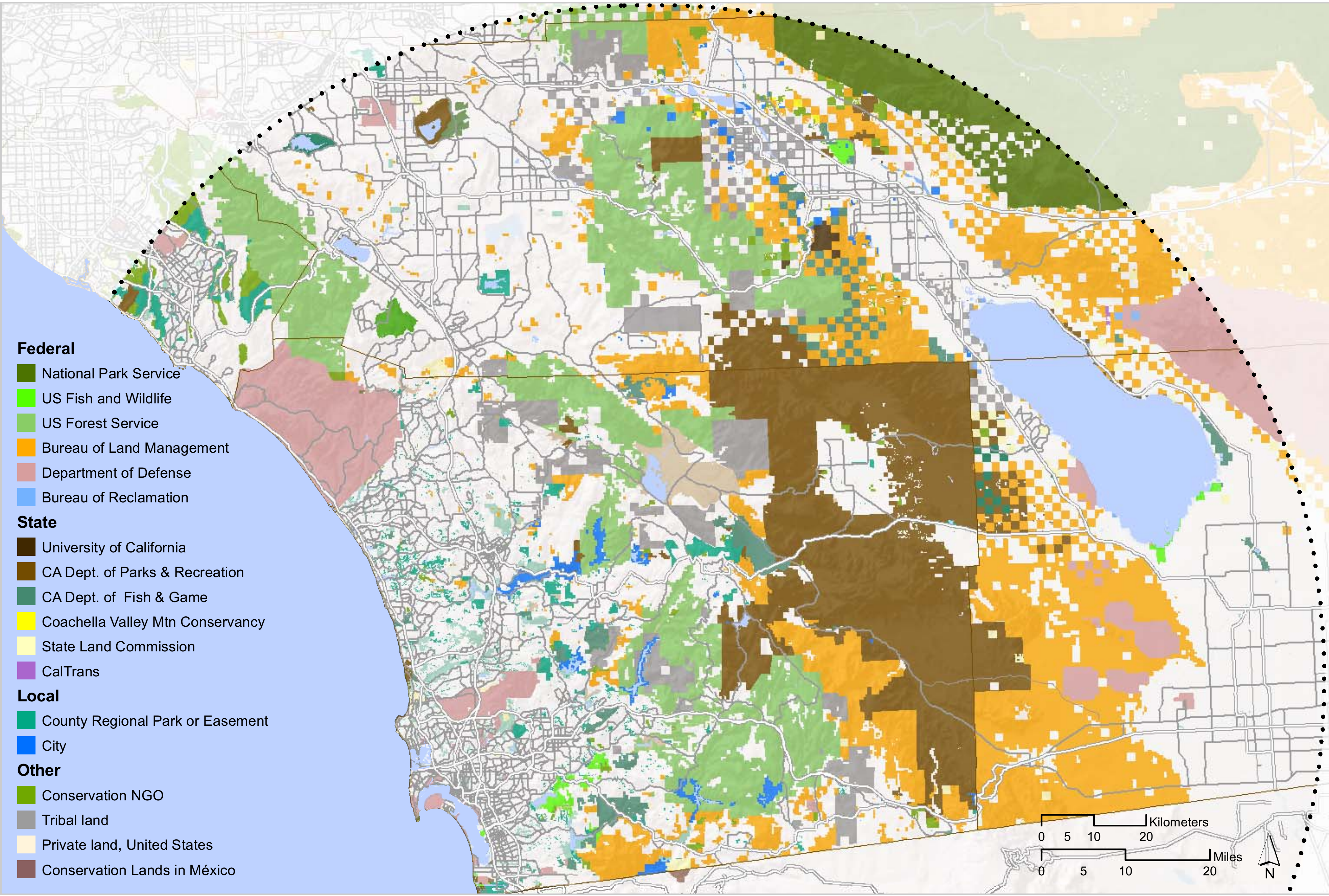


Figure 10. Public lands and lands with elevated protection

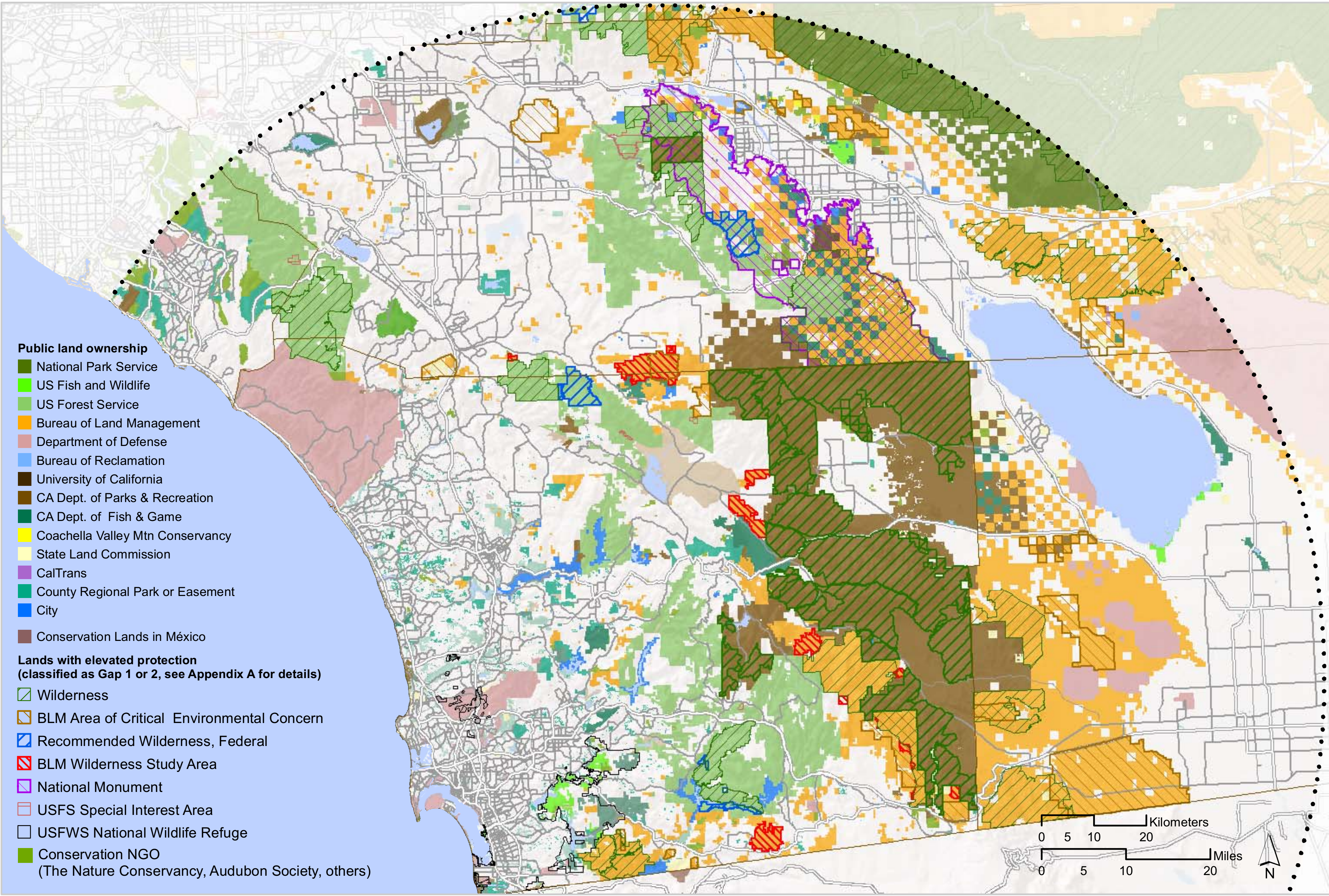


Figure B-1. Vegetation in the U.S. portion of the habitat suitability study area (agricultural lands were further differentiated as described in Appendix B)

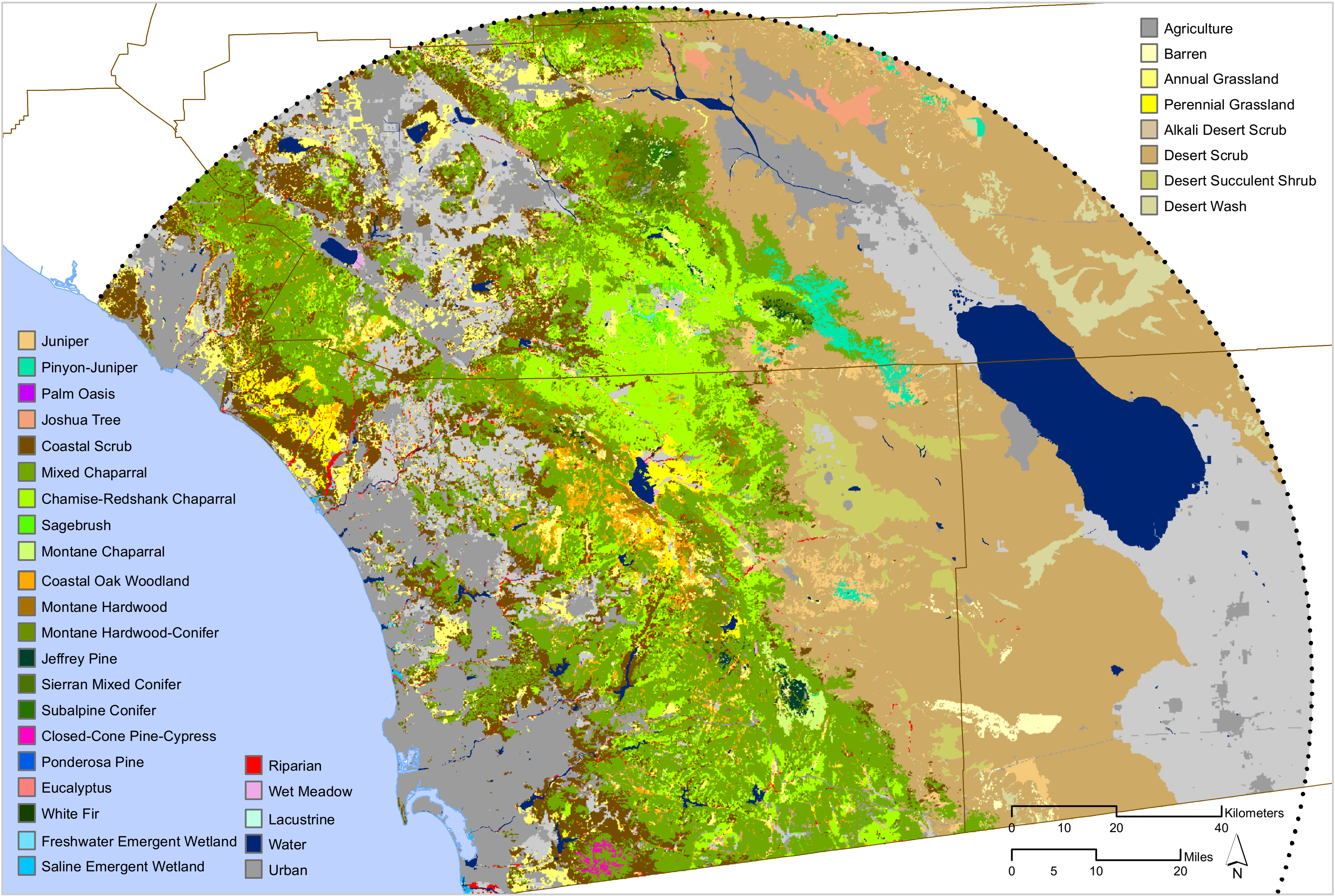


Figure B-2. Vegetation in the Mexican portion of the habitat suitability study area (agricultural lands were further differentiated as described in Appendix B)

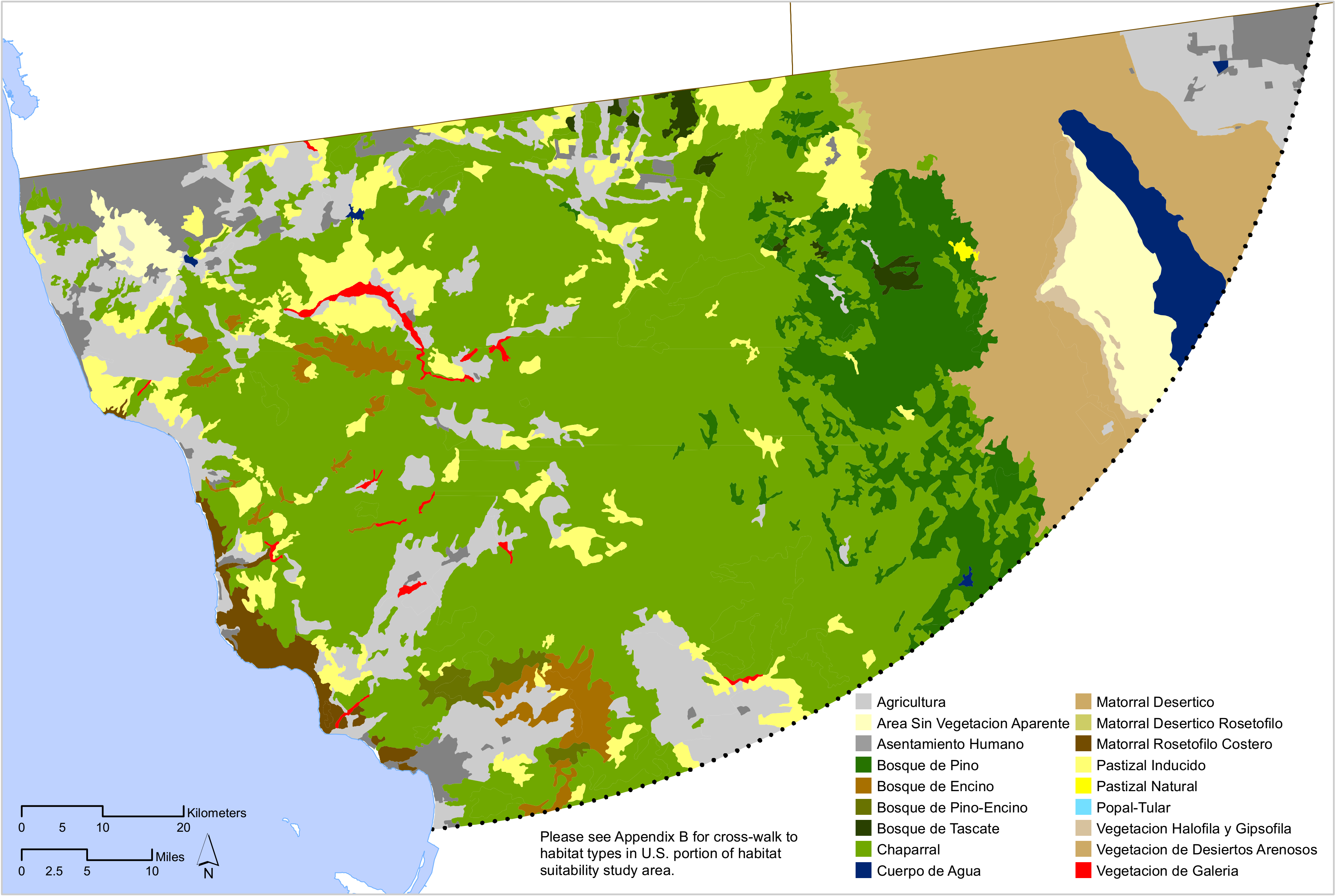
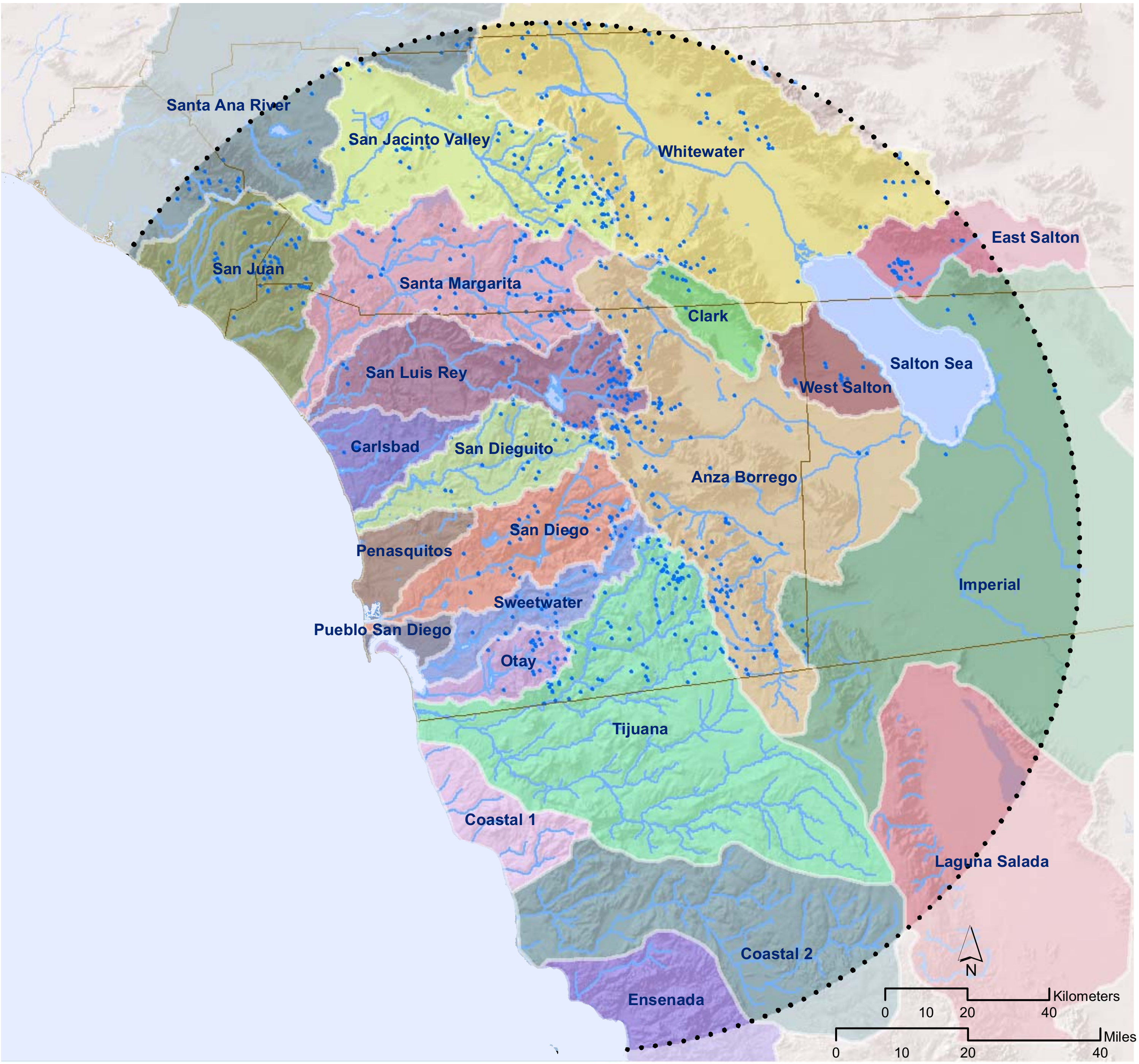


Figure B-3. Hydrology in the habitat suitability study area.



• Seep or Spring (Data were not available for lands in Mexico)

Water Body

Perennial River or Stream