# Wild Pig Management at Tejon Ranch

## Bren School Group Project 2014


MASTER OF ENVIRONMENTAL SCIENCE AND MANAGEMENT
BREN SCHOOL OF ENVIRONMENTAL SCIENCE & MANAGEMENT
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

**Group Project Members:** Jocelyn Christie, Emily DeMarco, Elizabeth Hiroyasu, Adam Kreger, Maxwell Ludington
**Faculty Advisor:** Naomi Tague


**April 10, 2014**

# Acknowledgements

We would like to thank everyone who has assisted and supported us through the duration of this project. We would especially like to extend our gratitude to the following people:

Faculty advisor: Naomi Tague (Bren School of Environmental Science & Management)

External Committee: Bruce Kendall (Bren), Frank Davis (Bren), and Kyran Kunkel (Tejon Ranch Conservancy)

Tejon Ranch Conservancy: Michael White and Tom Maloney

We would like thank the faculty and staff at the Bren School of Environmental Science & Management at the University of California, Santa Barbara for all of their support and assistance.

Finally, we would like to express our deepest gratitude to all of our friends and family who supported and encouraged us through this process.

As authors of this Group Project report, we are proud to archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.


Jocelyn Christie

Emily DeMarco

Elizabeth Hiroyasu

Adam Kreger

Maxwell Ludington


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The Group Project is required of all students in the Masters of Environmental Science and Management (MESM) Program. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

Naomi Tague

March 21, 2014

# ABSTRACT

Wild pigs have spread to 56 of the 58 counties in California since their introduction in the 1920's. Due to wild pigs' destructive behavior, this has resulted in significant ecological and economic impacts in the state. Despite wild pigs being listed as pest species in most states, California is one of three states that classifies them as large game species. This status creates unique challenges for managing wild pigs and reducing the damage they cause. We present an analysis of management options in California and the political context of wild pigs. The sale of wild pig tags provides an important source of revenue for the California Department of Fish and Wildlife tag sales, greater than one million dollars in 2012. We conducted preliminary research on wild pig management at Tejon Ranch, illustrating the challenges and trade-offs of managing wild pigs in California. We created a cost benefit analysis framework to compare different management strategies on the Ranch. We also carried out a pilot monitoring study to assess relative pig abundance in different vegetation classes. We found the greatest relative abundance of pigs in riparian and conifer areas in the summer season using camera traps placed along stream reaches and ranch roads. We found that damage was correlated with abundance of pigs only in riparian areas, however pig damage in other vegetation types was difficult to assess in the dry summer months. Based on our analysis we conclude that a strategic pig management plan for Tejon Ranch should focus on an adaptive management regime. This regime should include fencing high value areas to exclude pigs while engaging in strategic population reductions more widely through targeted trapping and increased hunting efforts. We recommend that a monitoring regime based on population and pig damage indices be implemented to improve future management efforts.

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# List of Abbreviations and Terms

Agreement: Ranch-Wide Agreement

ANOVA: Analysis of Variance

APHIS: USDA Animal and Plant Health Inspection Service

BMP: Best Management Practices

CBA: Cost Benefit Analysis

CDFW: California Department of Fish and Wildlife

Company: Tejon Ranch Company

Conservancy: Tejon Ranch Conservancy

EPA: Environmental Protection Agency

GIS: Geographic Information System

Pigs: Wild pigs (*Sus scrofa*)

PLM: Private Lands Management Program

PTI: Passive Tracking Index

QDM: Quality Deer Management Program

Ranch: Tejon Ranch

RWMP: Ranch-Wide Management Plan

SHARE: Shared Habitat Alliance for Recreational Enhancement

TRC: Tejon Ranch Company

USDA: United States Department of Agriculture

USFWS: United States Fish and Wildlife Service

WPMH: Wild Pig Management Hunt

# EXECUTIVE SUMMARY

## WILD PIGS IN CALIFORNIA

Wild pigs (*Sus scrofa)* are an invasive species that occur across the United States and in 56 of California's 58 counties. The wild pig range is continuing to expand in all areas that they occur, and their impacts are also expanding. Wild pigs are known to consume many different species of plants and animals and have profound effects on the landscape through their deleterious foraging practices, known as rooting. Wild pig populations are not expected to decline without intervention as pig populations have the potential to triple every year under optimal conditions (Barrett, 1978).

Wild pigs are classified as a big game species in California, Hawaii, and Florida. This status creates unique challenges to manage populations and mitigate the damage they incur across the landscape. Wild pigs are managed by the California Department of Fish and Wildlife (CDFW). The CDFW allows private landowners to harvest wild pigs through three methods: the encounter law, depredation, and hunting. The encounter law allows landowners to take wild pigs if they encounter them causing damage or threatening to cause damage to their property (FGC§4181.1). Depredation involves trapping of wild pigs and requires a permit issued by CDFW. Recreational hunting takes place across the state on public and private property. Recreational hunting is the most popular way to harvest wild pigs, and wild pig tag sales have been increasing since the 1990's. Currently, wild pig tag sales make up approximately 4.5% of the yearly CDFW, amounting to about $1.2 million.

## TEJON RANCH

Tejon Ranch is one of the most important and special places in California, and it represents 240,000 acres of preserved native grasslands, pine forests, oak woodlands, and Joshua tree wilderness. A unique agreement between the Tejon Ranch Company (TRC) and five conservation organizations protects 90% of the Ranch property from all future development. This agreement created the Tejon Ranch Conservancy, a non-profit organization tasked with managing and conserving the natural resources on the Ranch. The first Ranch Wide Management Plan (RWMP) was signed in June 2013, and formalized the duties of the Tejon Ranch Conservancy and best management practices on the Ranch, among other things.

Wild pigs were established on Tejon Ranch after the release of domestic pigs in the 1980's. Since then, the population has grown and is estimated to be between 1,000 and 4,000 pigs across the ranch. TRC currently operates a commercial hunting program on the Ranch, which includes the harvest of wild pigs. Hunt managers are currently working to harvest "as many pigs as possible" within the confines of the commercial hunt program (B. Grant, personal communication), however there is not currently an active management program for wild pigs. In the 2012-13 hunt season almost 1200 pigs were harvested on the ranch. Despite the robustness of the hunting program, this project has shown that recreational hunting is not enough to manage and control the wild pig population on the Ranch.

## Pilot Monitoring Program

The Bren group conducted a pilot monitoring study in the summer 2013. Over the course of this study, we identified a monitoring strategy to be implemented throughout the year on the Ranch. Bren students monitored riparian and terrestrial zones using camera traps and 10m x 10m damage plots to estimate indices of abundance and damage. In the terrestrial areas, a multiple regression was used to examine the relationships between pig abundance and elevation, distance to a stream, distance to an alternative water source, and other mammal activity. Our analysis revealed a statistically significant relationship between pig abundance and elevation. Analysis of Variance (ANOVA) was used to examine the relationship between damage and different habitat types that were sampled (grassland, savannah, woodland, chaparral, and conifer). We found that there was a statistically significant difference between damage caused in different habitat types. Riparian habitats were the most commonly damaged. It is important to note, however, that our pilot study was limited to the dry summer months and we feel that it is important to conduct these studies in all seasons in order to establish the seasonal relationships between pig damage and habitat type. In the riparian zones, we found a statistically significant relationship between pig abundance and damage. This has important implications for management because damage is much easier to monitor than pigs themselves, and if this relationship can be seasonally linked to other habitats, then the Conservancy can use damage plots to estimate the pig population on the Ranch.

## Cost Benefit Analysis

A cost benefit analysis was conducted to establish the relative costs and benefits of each management strategy available to the ranch. In this analysis, we focused on three main management strategies: hunting, depredation, and exclusion fencing. We treated hunting as a baseline estimate because it is a reserved right for the Tejon Ranch Company, therefore the costs and benefits were not quantified in our analysis. The other options are assumed to take place in conjunction with hunting efforts. For depredation and fencing we made assumptions about the success rate of each method, the cost associated with implementing each method, and how much each method could improve the value of the land. The cost benefit framework created in this analysis can be adjusted to reflect changes in management strategies. Our results indicate that hunting is the most cost effective control method on lands where pig control efforts can raise the value by up to $500 per acre. On lands where the value can be raised above $500, and up to $3,100 per acre, depredation is the most cost effective control method. On lands where the value can be increased more than $3,100 per acre, exclusion fencing is most cost effective method.

## Recommendations

Through this project we have come up with a series of recommendations for the Tejon Ranch Conservancy for wild pig population on Tejon Ranch. We recognize that any management regime adopted requires a working, collaborative relationship between the Conservancy, TRC, and the managing agency, CDFW.

### Recommendation one: Spatially define damage control efforts

We recommend that the Conservancy identify and classify primary and secondary priority areas for protection from wild pig damage.

### Recommendation two: Monitoring

We recommend that the Conservancy continue a monitoring program that monitors indices of wild pig abundances and wild pig damage. This monitoring program should occur throughout the year in order to reflect any effects of seasonality. We recommend that the Conservancy identify quantitative damage reduction objectives to guide their wild pig management program.

### Recommendation three: Implement pig damage controls

After an extensive literature review and a review of the different management strategies available, we recommend that the Conservancy adopt a strategy that is a combination of targeted hunting, depredation trapping, and exclusion fencing. Adopting a targeted hunting program and a night hunting program to supplement the current hunting program on the ranch, by targeting female pigs and piglets can help to reduce population densities. Exclusion fencing should be erected in highest priority areas. Finally, a depredation effort should be implemented in secondary priority areas to reduce pig damage. The cost benefit framework outlined in this project is designed guide to implementation of each damage control option.

### Recommendation four: Pig Action Network

Because wild pigs impact lands across the state, the Conservancy can partner with other affected landowners to collaboratively work together to reduce the impacts of wild pigs. Given the increased impacts from wild pigs across the state, this appears to be an opportune moment to pressure CDFW for increased autonomy in terms of managing pigs. The pig action network can also lobby to change the status of wild pigs from a big game species to a nuisance species, which would help reduce many of the challenges of management that exist within the current legal framework.

# CHAPTER 1: INTRODUCTION

## 1.1 TEJON RANCH OVERVIEW

Tejon Ranch is located approximately 60 miles north of Los Angeles and encompasses 270,000 acres of native grasslands, pine forests, and oak and Joshua tree woodlands. The Ranch represents some of the most spectacular and ecologically important wildlands in California and is at the intersection of four ecological regions. The 2008 landmark conservation agreement between the Ranch's owner, the Tejon Ranch Company (TRC), and five leading conservation and environmental groups - Sierra Club, National Audubon Society, Natural Resources Defense Council, Endangered Habitats League, and the Planning and Conservation League - permanently protected 240,000 acres via a conservation easement while allowing the remaining 30,000 acres to be slated for future development. The conservation agreement created the Tejon Ranch Conservancy, which is responsible for protecting and managing the open space on the Ranch. In June 2013, the first Ranch-Wide Management Plan (RWMP), a collaborative management strategy between the TRC and the Tejon Ranch Conservancy, was signed into practice.

### 1.1.1 WILD PIGS ON TEJON RANCH

Located in the heart of southern California, Tejon Ranch is home to a host of wildlife, including herds of antelope and elk, a plethora of bird species, and several iconic endangered, threatened, or special status species. Among the wildlife on the Ranch are herds of wild pigs (*Sus scrofa*) that are believed to have been accidently released on the Ranch in the late 1980s from a neighboring pig farm. This original population became feral and has spread throughout the Ranch, creating a wild population. The presence of wild pigs has directly impacted the quality of Tejon Ranch's ecosystems: pigs root up the soil and damage habitat throughout the Ranch. They are also known to eat numerous species of bulbs, roots, plants, and animals, and they can negatively impact water quality. The destructive population is not expected to decline without intervention; under optimal conditions, pig populations have the potential to triple every year as mature sows typically birth 2 litters of 5 to 6 piglets each year (Barrett 1978). The ecology of wild pigs is discussed further in Chapter 3. TRC currently operates a commercial wild pig hunting program on the Ranch, but there is no other active management of wild pig populations.

### 1.1.2 HISTORIC USES AND RESERVED RIGHTS

Prior to being settled, it is believed that Native Americans cultivated the land on Tejon Ranch for agricultural purposes. Following settlement, Tejon Ranch was broken into Spanish land grants, and the entirety of the ranch is comprised of three different grants. Today, 250,000 acres of the Ranch is leased for cattle grazing with an additional 6,000 acres dedicated to agriculture. Both ranching and agriculture are defined as "reserved rights" of the TRC. Filming, hunting, cement and oil production, and private recreational use are also designated as reserved rights. TRC's reserved right to hunt has significant implications on the way that wild pigs can be managed on the Ranch.

## 1.2 SIGNIFICANCE

Managing wild pigs presents challenges in numerous parts of the U.S. and throughout almost all of California. Wild pigs are found in 56 of California's 58 counties. The population in California is estimated to be between 200,000 and 1 million and the total U.S. wild pig population is estimated to be over 5 million (Mayer & Brisbin, 1991). Preliminary analysis of pig harvest (R. Sweitzer, UC Berkeley, unpublished data) shows that pigs extended their range in California by more than 7,000 square miles between 1992 and 2004. Rough estimates based on literature and local hunting guide knowledge put the wild pig population between 1,000-4,000 individuals on Tejon Ranch, and it is believed that the pig populations are spread throughout the entirety of the Ranch.

Wild pigs can be highly destructive animals. Underground bulbs and insects compose a significant portion of their diet and they root up soil to access these food sources (Barrett 1978). This feeding behavior, compounded by their abundance throughout California, means that the animals are causing damage to ecosystems across the state. In areas where high-density wild pig populations have emerged, they have significantly damaged protected lands and agricultural resources (Richard A. Sweitzer, Van Vuren, Gardner, Boyce, & Waithman, 2000). Pigs also threaten livestock by competing for food sources, directly predating livestock, and serving as vectors for infectious disease transmission. Wild pigs are known to carry up to 30 bacterial and viral diseases and up to 37 different parasites (Choquenot, McIlroy, & Korn, 1996) While disease transmission from pigs has not been documented on Tejon Ranch, the pigs are causing significant observable, although yet to be quantified, ecological damage due to their rooting behavior. There is also anecdotal evidence that pigs are encroaching on cattle operations. Recent reports from surrounding areas also state that wild pigs have been seen preying on calves in Kern county (Julie Finzel, 2013). As such, better management of the population is critical to preserving the fragile ecosystems on the ranch and the various economic interests of the Tejon Ranch Company.

Unlike most other states, California has classified wild pigs as big game species instead of a pest species. The state lacks a comprehensive wild pig management plan, placing other private lands, reserves, and parks around the state at risk of wild pig damage as the pigs' range continues to expand. Comprehensive management plans that work within the legal framework of the state are very rare, and there is a need for cost effective strategies on private lands and protected public lands (Richard A. Sweitzer et al., 2000). Indices of wild pig abundances and damage as well as a cost analysis of management options developed by this project may be extrapolated and used as a model for controlling wild pigs on public and private lands throughout California and the U.S.

## 1.3 PROJECT OBJECTIVES

The overall objective of this project is to assist and inform the Tejon Ranch Conservancy in the development of a wild pig management plan. In the course of this report, we will address the following issues:

### 1. ASSESSMENT OF REGULATORY POLICY AND FRAMEWORK FOR MANAGING WILD PIGS IN THE CONTEXT OF THE STATE OF CALIFORNIA AND ON TEJON RANCH:

- What are the regulatory, policy, and land use contexts of wild pig management in California?

- What are the implications for Tejon Ranch?
- What does this context mean for managing wild pigs?

## 2. Assessment of pig abundances, spatial distributions, and ecological effects in the state of California and on Tejon Ranch:

- What are the types of ecological impacts associated with wild pigs?
- What habitat types are wild pigs most commonly located in?
- What habitat types do wild pigs have the greatest impacts on?

## 3. Assessment of economic effects of wild pigs in California and on Tejon Ranch:

- What are the economic effects of wild pigs in the state and on Tejon Ranch?
- How can these impacts be quantified?

## 4. Monitoring Techniques:

- What wild pig monitoring techniques are available to establish abundance and damage estimates by wild pigs on Tejon Ranch?
- How do their practicality, cost, and utility vary?

## 5. Management options:

- What wild pig management techniques are available to the Tejon Ranch Conservancy?
- What have their practicality, cost, and efficacy been in other relevant settings?
- How do these various management techniques fit within California's regulatory, policy, and land use context?
- What constraints (social, economic, or practical) exist for wild pig management at Tejon Ranch?
- What are the relevant trade-offs between management options?

# CHAPTER 2: CONTEXT

## 2.1 ORIGINS AND NATIVE RANGE

*Sus scrofa scrofa* is the common ancestor of boars, feral pigs, and domesticated pigs. Today these animals are found around the globe; their natural range (Figure 1) includes Europe, most of Asia, and the Northwest coast of Africa (Mayer & Brisbin, 1991). Wild boars, also known as Eurasian wild boars or Russian boars, are direct descendants of *S. scrofa scrofa* and have never been domesticated. Modern domesticated pigs (*S. scrofa domesticus)*, on the other hand, were selectively bred from *S. scrofa scrofa* by humans in Europe and Asia (Mayer & Brisbin, 1991).

Feral pigs, occupying the area between these two extremes, are wild pigs that have some amount of domestication in their ancestry. This category can include pigs that have recently escaped or been released into the wild or offspring from pigs that have been wild for one or more generations. Hybrid pigs exist that have recent ancestry of both *S. scrofa domesticus* and *S. scrofa scofa*. These distinctions are more than just semantics and interesting history. Good physical, genetic, and behavioral reasons exist for recognizing and understanding these differences, but widespread hybridization has made it difficult to know the origin of any given pig population. Still, there are clues. Pig populations with wild boar ancestry tend to be larger with long skulls, mottled coloration, and thick, curly hair. Pig populations with domesticated pigs for ancestors tend to be smaller and black, with broader skulls and short, straight hair (Mayer & Brisbin, 1991). All three types of wild pigs, including feral pigs, hybrid pigs, and Eurasian wild boar, currently exist in the U.S. For the purpose of this report, we refer to the pigs present on Tejon Ranch as "wild pigs."

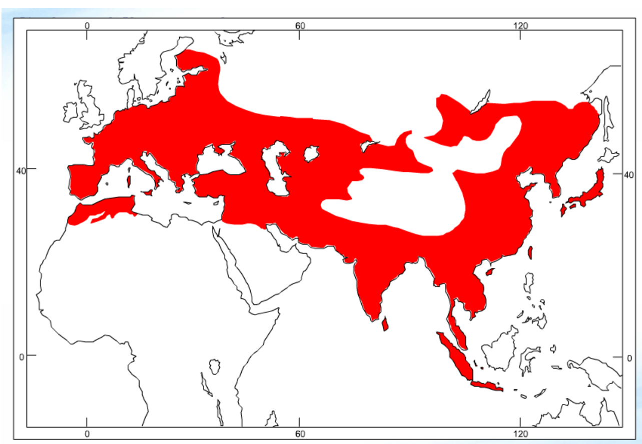


**Figure 1 Native range of S. scrofa scrofa (Mayer, 2012).**

## 2.2 HISTORY AND DISTRIBUTION IN THE UNITED STATES

Hawaii has the longest history of wild pig populations in the U.S. After pigs were introduced to the Pacific islands, they had reached Melanesia and Polynesia by 3500 years ago (Long, 2003). Around 1000 A.D., pigs were introduced to Hawaii by Polynesians (Mayer & Brisbin, 1991).

Like other domesticated animals, pigs accompanied European settlers on their journey to the New World. In 1493, Columbus introduced pigs to the West Indies, and in 1593, DeSoto introduced them to Florida. Over time, some of these domesticated pigs escaped and became feral. Pure Eurasian wild boars were also introduced to the U.S. in the late 1800s to stock game preserves around the country. As with domesticated pigs, some of these individuals also escaped from the preserves into the wild.

Wild and feral pig populations now exist throughout the United States, and their range has been expanding. USDA-APHIS-Wildlife Services tracks wild pig populations throughout the country. Figure 2 below shows the locations of recorded pig populations in 1982 and 2012. It is believed that in 1982 wild pigs were found in only a few counties in 17 states, but by 2012, they were found in at least 38 states. Currently, dense wild pig populations exist in the Southeast, lower Midwest, and California.

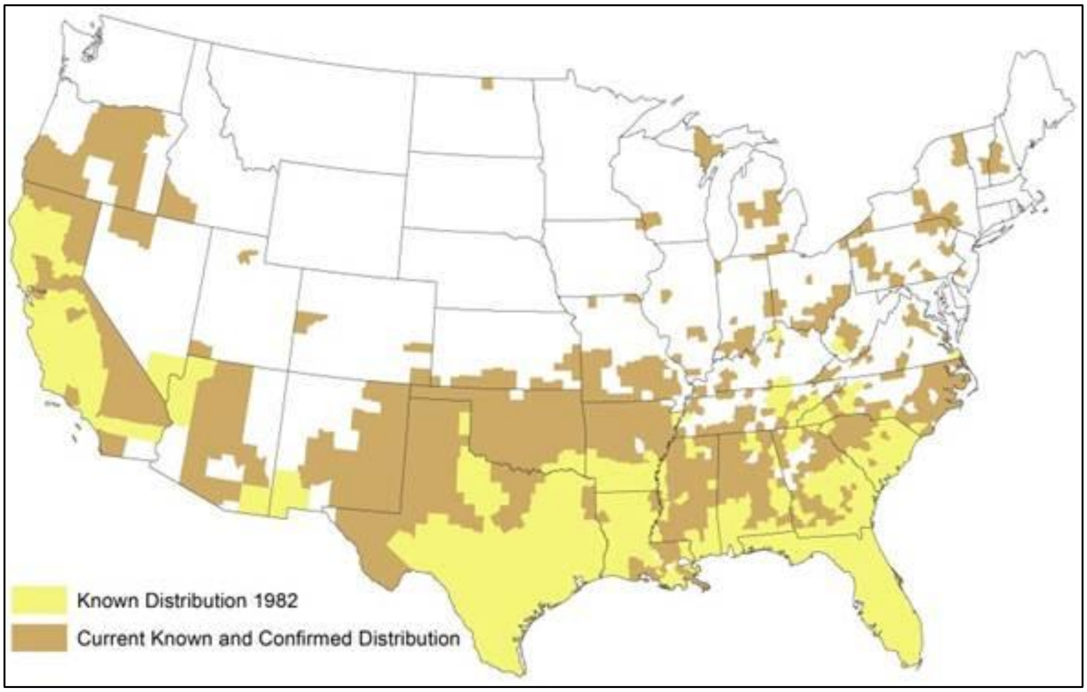


**Figure 2 Wild Pig Populations in the U.S. 1982 – 2012 (Source: USDA – Wildlife Damage Management)**

## 2.3 History and Distribution in California

Pigs have been present in California since Spanish settlers first brought domesticated swine to the coastal portions of the state in 1769 ((R. H. Barrett, 1981). Many of these pigs escaped and became feral, and resident populations expanded throughout the coastal oak woodlands of the state. Wild boars were first introduced to California in Monterey County in the1920s and eventually interbred with their feral kin (Kreith 2007). Since the State of California classified wild pigs as a big game species in 1957, pigs have consistently spread throughout the state and now occupy 56 of California's 58 counties (Figure 3). Dispersal has been by both natural movement as well as relocation by landowners attempting to generate hunting opportunities (R. H. Barrett, 1981).

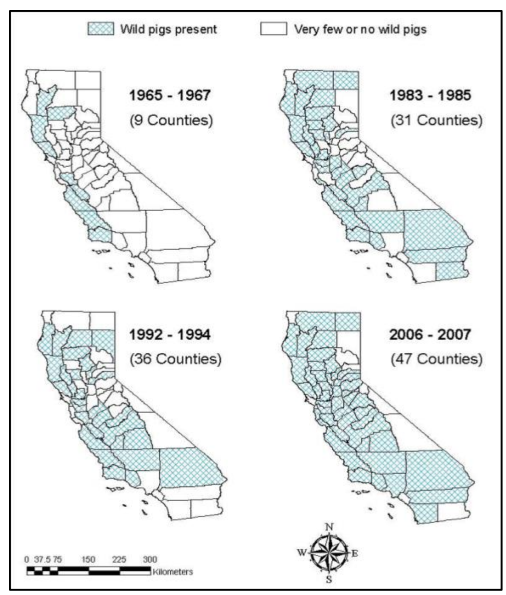


**Figure 3 Presence of wild pigs throughout the state of California (Sweitzer and McCann, 2007)**

## 2.4 Regulatory Framework

### 2.4.1 Nationwide Framework

In the United States, wild pigs are classified by state wildlife agencies in a variety of ways. Due to the economic and environmental damage caused by the species, most states consider the pigs to be invasive pests, meaning that they can be harvested throughout the year and removal methods can include trapping as well as nighttime hunting without state permission. Three states, California, Hawaii, and Florida, however, classify wild pigs as "big game" species. This classification gives the states more control to regulate pig populations, however it decreases landowners' options for controlling pig populations, notably by requiring special permits to engage in trapping and night hunting efforts.

Some states have recently reclassified pigs as pest species. Tennessee, in particular, is an interesting case study with potential relevance to wild pig management in California. During the last 15 years, pigs in Tennessee have spread from 15 counties to nearly 80 of the state's 95 counties. In 1999, the state wildlife resources agency attempted to control the population expansion by opening a statewide wild pig season with no bag limit. As the agency's website notes, however, "unfortunately, it was during this period of unlimited hunting that the wild hog population expanded the most. Disjointed populations of hogs began to occur in areas of Tennessee where they had never existed before as the result of illegal stocking by individuals whose goal was to establish local hunting opportunities." In 2011, in response to increased reports of property damage, Tennessee enacted new regulations reclassifying wild pigs as a "destructive species to be controlled by methods other than sport hunting" ("Wild Hog Regulations - Tennessee Wildlife Resources Agency," 2013).

In 2011, North Carolina also implemented new rules for hunting and trapping of wild pigs. The state classified all wild pigs as feral and removed their game classification. Under the new trapping rules, trappers must have a free North Carolina Wildlife Resources Commission issued trapping permit in addition to a hunting or trapping license. Previously, wild pigs could be trapped only with a depredation permit available "on the basis of economic damage, threat to human safety, or documented overabundance." The USDA reports that pigs in the state cause an estimated $800 million in damage every year (Hubbard, 2011; "Feral Swine Trapping - North Carolina Wildlife Resources Commission," 2013).

### 2.4.2 California Framework

Unlike most states, California manages wild pigs as a big game species rather than a pest species, and commercial and recreational hunting of pigs is widespread and popular. This classification has important implications for their management, as more stringent regulations apply to their harvest than if they were managed as a pest species.

Before 1950, wild pigs were unclassified under state law, and they could be killed with no restrictions. In 1957, the State Fish and Game Commission reclassified wild pigs as game animals and identified hunting seasons, bag and possession limits, methods of take, and conditions for using dogs (J. Waithman et al., 2001). At the time, pig populations in the state were limited to 10 coastal counties. Rapid population growth and geographic expansion, coupled with the destructive habits of wild pigs has forced management policy to change.

In 1991, concern over pig damage to private property and natural resources led California Department of Fish and Wildlife (CDFW) to take steps to increase hunting pressure on the animals. The agency began forcing hunters to purchase booklets of five tags rather than single pig tags with the hope of increasing hunting pressure on the population (Barrett, Reginald H. 1993). In 1997 the state legislature passed the McPherson (Encounter) Law which allowed "landowners or agents acting on behalf of those landowners to kill any pig found or threatening to cause damage on site, without a hunting license or a state issued depredation permit (Kreith 2007)." The law opened up new options for landowners to take additional steps to control pig populations on their lands.

Current policy allows landowners to control pigs via three primary methods:

**1) Private land hunting**

Hunters in possession of state issued license and tags may harvest wild pigs on private lands in accordance with state law. Hunting is the most common wild pig population control method in the United States and abroad, but it has limits to effectiveness. In Australia and New Zealand, studies have shown that it may be necessary to eliminate at least 70% of the population in a given year to reduce or maintain population numbers (Dzieciolowski, Clarke, & Frampton, 1992, Caley & Ottley, 1995, Saunders, 1993. In California, moderate to high hunting pressure has been found to reduce the density of wild pig populations in localized areas (Richard A. Sweitzer et al., 2000), at least temporarily. It is possible however, that harvest of pigs through hunting can stimulate population growth by increasing access to resources for the remaining pigs (Fernandez-Llario, Matoes-Quesada, Silverio, & Santos P., 2003, Massolo & Mazzoni della Stella, 2006).

**2) Depredation permits**

The use of depredation permits continues to be a common form of CDFW-sanctioned wild pig control for private landowners. The CDFW issues depredation permits to landowners whose property is being damaged by pigs. A CDFW agent verifies that the damage is occurring and issues a depredation permit that allows the landowner to take measures to control the pigs. The permit specifies the length of time through which the permit is active (up to one year) and the number of pigs that may be killed (no maximum). Depredation permits are issued for any lands where the owner may prove that "damage" is occurring. Permits may be renewed indefinitely.

What constitutes damage is largely dependent on the agent issuing the permit. Interviews with CDFW agents indicate that damage is usually defined as any effects of the pigs that can be lead to economic losses, or cause exceptional environmental damage for the property owners. Hence, riparian areas and pasturelands are eligible for depredation permits if pigs are present, while oak woodlands generally are not. However, some agents within CDFW state that "damage is damage" whether it is explicitly economic or not, while others state that the landowner must prove economic damage.

A depredation permit specifies the agents (maximum of 3) who may carry out the depredation of the pigs. Corporations, agencies, employees of the landowner, or individuals may be listed on the permit. The United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) Wildlife Services division is available to assist landowners who need assistance carrying out the depredation. Depredation permits allow the landowner to engage in pig removals that are generally not allowed by hunting tags alone. The two most common additional controls are the use of traps and night hunting to control the populations. Carcasses from depredation efforts may be left in the field if conditions prevent the beneficial use of the carcass. Depredation permit holders must report the results of their efforts including date taken, sex, and number taken by the 15th of each month.

Wildlife Services conducts wildlife removal or depredation in approximately 39 counties in California on both public and private lands. Each county has a specialist who is in charge of verifying that the damage reported was caused by pigs. Then he or she organizes a team to do the removal process. In conversations with Wildlife Services representatives, we learned that there is an increasing trend in the number of requests to remove pigs across the state. In Wildlife Service's opinion, this increasing trend means that damage done by pigs in the state is increasing. However, the increase in total damage in the state could be caused by an increase in the total number of pigs in the state, or it could be caused by pigs moving into areas of the state where they cause more damage (i.e. agricultural fields or neighborhoods). Additional data is needed to verify the trend.

With the approval of the Tejon Ranch Company, the Conservancy could obtain a depredation permit for targeted areas of the Ranch, such as in sensitive riparian zones, in order to minimize the amount of damage that pigs do in those areas. If the Tejon Ranch Conservancy obtains a depredation permit from CDFW, the Conservancy can identify one of their three allotted agents to be Wildlife Services, thus broadening the number of people allowed to remove pigs beyond three individuals. Wildlife Services then conducts a site visit to verify that the damage reported was done by pigs and signs an agreement with the Conservancy. At that point cage, corral, or bait traps are set out to trap pigs. Wildlife Services operates under depredation permit guidelines, meaning they can hunt at night, use night vision goggles, special firearms, and spotlights. There would be a cost for their time, supplies, and equipment, and further cost estimates can be discussed once a depredation permit has been obtained.

Wildlife Services could also aid the Conservancy through a trap and tag program to learn more about pig movement and behavior. In this case, a scientific collection permit would need to be obtained by the Conservancy from the CDFW. Once again, Wildlife Services could help with the trapping and tagging, but there would be a cost for their time, supplies, and equipment. Trap and tag efforts to learn more about pig ecology are discussed further in Chapter 3.

**3) Encounter Law**

Landowners may immediately kill any pigs they see on their land that are causing, or threatening to cause, damage to their property without first obtaining a hunting tag or depredation permit. Any pig removal conducted in accordance with this law must be immediately reported to CDFW.

### 2.4.3 Hunter Surveys

In order to gain a better understanding of the current attitudes and practices of recreational wild pig hunters on the Ranch, a survey was developed and distributed to hunters in summer and fall 2013. The anonymous and voluntary surveys were created to gather information about hunters' knowledge of wild pigs on the property that could be used in developing effective pig management strategies. Copies of the distributed survey can be found in
Appendix 1: Wild Pig Survey for Hunters and Guides.

#### Survey Results

There were twenty-six respondents to the survey, of which, 24 were from California, one from Arizona, and one did not specify. Respondents have hunted pigs in California for 1-24 years, and an average of 8.1 years. Fifty-two percent of respondents hunted pigs in California in the last five years. The majority of respondents (68%) hunted on Tejon Ranch specifically, while 32% hunted in other parts of California. Of those surveyed, 96% of hunters interest in wild pig hunting has either increased or remained unchanged over time (56% and 40% respectively), while only one respondent has had a reduction in interest in wild pig hunting.

On Tejon Ranch, 105 boars and 78 sows were harvested by respondents in the 2012-2013 hunting season. In California, excluding Tejon Ranch, respondents harvested six boars and nine sows in the 2012-2013 hunting season. 53.33% of hunters participated in unguided wild pig hunts, 36.67% participated in wild pig management hunts, 6.67% participated in guided weekday hunts, and the remaining 3.33% participated in guided weekend hunts in the last year.

Approximately 54% of respondents believe that the wild pig population at Tejon Ranch has remained the same in the last year, only one respondent believed that the wild pig population had grown in the last year. Looking over the last three years, respondents were more uncertain with 19% who believed the population was lower, 31% believed the population was about the same size, 11.5% believe it had grown, and 38% were unsure. Compared to five years ago, about 50% of respondents were unsure and 34% believed the population was lower than in previous years. Of those surveyed, only one respondent believes that the current wild pig population on the ranch is too large, while 40% believe the population is about the right size and 56% believe that the population is too small (Figure 4).

When presented with the statement "Wild pigs are native to California", 19% strongly disagree, 54% disagree, 8% are unsure, and 19% agree. Despite this, approximately 84% of respondents agree or strongly agree that wild pigs are a "welcome addition to the number of big game species" that can be hunted. Only two respondents to the survey agree that they will "only hunt for boars". Nineteen percent of respondents strongly disagree with the statement "I worry about problems wild pigs might cause Tejon Ranch", 42% disagree, 27% are unsure, and 12% strongly agree. Approximately 68% of respondents strongly disagree or disagree with the statement "I worry about problems wild pigs might cause in greater California", 19% are unsure, 4% agree, and 8% strongly agree with this statement.

Eighty-five percent of respondents strongly disagree or disagree that wild pigs "detract from hunting opportunities for other game", and 72% believe that "hunting can stabilize wild pig populations." The majority of respondents (85%) do not believe that trapping and culling should be used to help control wild pig populations. Two respondents strongly agree or agree with the statement "I would hunt sows or piglets to help manage pig populations," 77% strongly disagree or disagree with this statement. Most respondents believe that wild pigs should be managed for a healthy pig population (84%), while only 31% and 24% strongly agree or agree that wild pigs should be managed for a healthy ecosystem or minimizing pig damage, respectively.

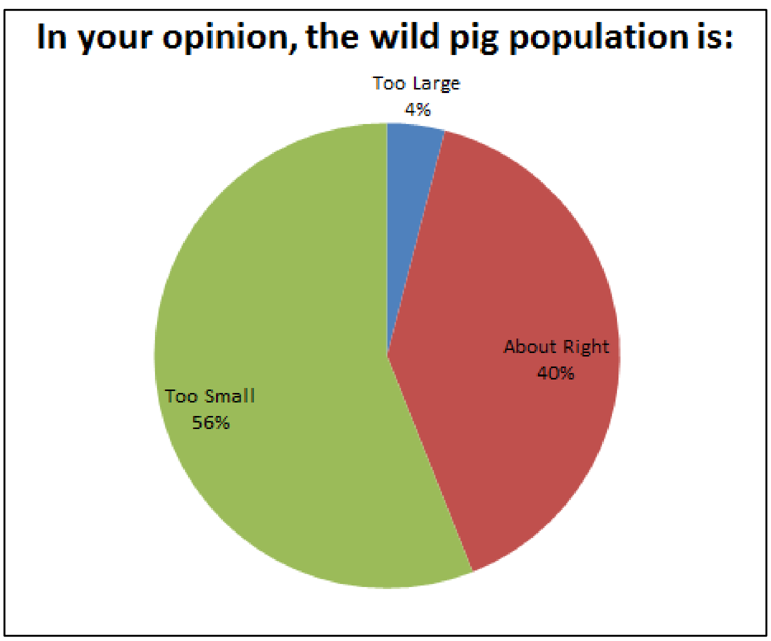


**Figure 4 Opinions of the current size of wild pig populations on Tejon Ranch (n =26)**

No respondents would accept a lower pig population to increase the size of boars. However, 38% will accept lower pig numbers in order to increase the numbers of other game, 27% are unsure and 34% disagree or strongly disagree. 50% of respondents will not accept lower pig populations to improve habitat quality or reduced damage from pigs.

64% of respondents are satisfied with wild pig hunting seasons and hunt options on Tejon Ranch, and of the remaining respondents, 24% are unsure and 12% disagree. Four respondents disagree or strongly disagree with the statement "I am completely satisfied with the rules of hunting wild pigs at Tejon Ranch", while 19% were unsure, and 62% strongly agreed or agreed. 42% of respondents were not satisfied with the price of the hunt, 35% were unsure, and 24% were satisfied. 42% of respondents were satisfied with the number of boars seen, while 23% were unsure, and 34% were not satisfied. 50% of respondents were not satisfied with the size of boars seen, 23% were unsure, and 27% were satisfied.

## Discussion

It is important to note that survey respondents are primarily participants in management hunts and not higher-paying private clients. Our understanding of the current attitudes of hunters on Tejon Ranch could be improved if we obtained a sample of all participants in the hunting program at the Ranch.

Almost 100% of survey respondents reported that their interest in wild pig hunting has increased or remained the same over time. This shows that pig hunting, unsurprisingly, is of great interest to the Tejon Ranch clientele and interest will most likely remain the same, if not increase. On Tejon Ranch, 183 wild pigs were harvested by respondents in the 2012-2013 season, this represents approximately 15% of the total harvest for the year. Of those who responded, only 10% participated in guided weekday or weekend hunts, suggesting that a majority of the harvest represented in our survey takes place during management hunts and unguided hunts.

Over half of respondents believe that the wild pig population has remained the same in the last year. There is a small fraction of respondents (19%) who believe the population has shrunk in the last three years, although many were unsure. Of those surveyed, only one respondent believed that the current wild pig population on the ranch was too large, while 56% believe that the population is too small. This suggests that wild pig hunters believe that the population should be larger, and management to reduce wild pig populations may not be favorable with this demographic. It seems that many of those surveyed understand that wild pigs are not native to California (73%), however almost all respondents (84%) believe that wild pigs are a "welcome addition to the number of big game species" that can be hunted.

Thirty-four percent of respondents were unsatisfied with the numbers of boars seen, and 50% were unsatisfied with the size seen. This suggests that the Tejon Ranch hunting program could consider managing boar populations for numbers and size. Reducing population sizes may increase physical sizes of boars, however, reduced population sizes would most likely lead to a reduction in hunter success.

Approximately 60% of respondents strongly disagree or disagree with the statement "I worry about problems wild pigs might cause at Tejon Ranch." An even greater number, 68% disagree or strongly disagree with the statement "I worry about problems wild pigs might cause in greater California". Most hunters (~85%) believe that wild pigs should be managed for a healthy wild pig population rather than being managed to reduce ecological damages. This illustrates the priorities of clients of the Ranch, which are to have successful hunts. Therefore, if recreational hunting is to be used as a management tool, there will need to be collaboration between hunters and the Conservancy. Consensus among respondents is spread about whether or not wild pigs are a source of disease, with approximately 27% who strongly disagree or disagree, 35% who are unsure, and 38% who agree or strongly agree. Because pigs can be carriers of up to 37 different bacterial or viral diseases, this suggests that an education program of the risks of wild pigs to agriculture and to hunters may be an important component in the long term.

Many surveyed hunters do not believe that wild pigs detract from hunting opportunities for other game, and most believe that hunting can stabilize wild pig populations. However, 38% of respondents are willing to accept lower pig populations if this results in an increase in other game species on the ranch. Interestingly, only two respondents agree or strongly agree that they would be willing to hunt sows or piglets to help manage pig populations. Many of those surveyed have harvested sows but none had killed a piglet. While this could suggest a lack of opportunities to shoot piglets, we believe it is most likely that these hunters oppose harvesting piglets specifically. This may make it more difficult to implement a management hunting program. As literature has suggested, it is most important to target sows and piglets to reduce pig densities (Toïgo, Servanty, Gaillard, Brandt, & Baubet, 2008).

### Survey Conclusions

Hunter surveys provide insights about the attitudes toward current practices on the Ranch and are useful to determine the feasibility of altering management practices. This preliminary survey provides some insights about hunter willingness to harvest different ages of wild pigs. It is also clear from this survey that an educational component to teach hunters about the problems associated with wild pigs might be necessary to reduce hunter resistance to changes in management practices. It would be helpful to distribute this survey more widely in order to gain a clearer understanding of the attitudes of all clients on the Ranch.

# CHAPTER 3: WILD PIG BIOLOGY AND ECOLOGY

The biology and ecology of wild pigs contribute significantly to their success as an invasive species. The average lifespan of a wild pig is between 4-5 years (R. Taylor, 1991). They can be diurnal or nocturnal, depending on seasonality and nearby human activity, however warmer temperatures and high human activity tend to make pigs more nocturnal (Kurz & Marchinton, 1972, Reginald H. Barrett, 1978, Singer, 1981). Wild pigs can run at speeds up to 30 mph and can jump three to four feet high. They use all five senses but depend most heavily on smell; they can smell between five to seven miles away over land surfaces. They rely secondarily on sight and have fair hearing (Mayer, 2012). These physical and behavioral adaptations help them to evade predators.

## 1 WILD PIG REPRODUCTION

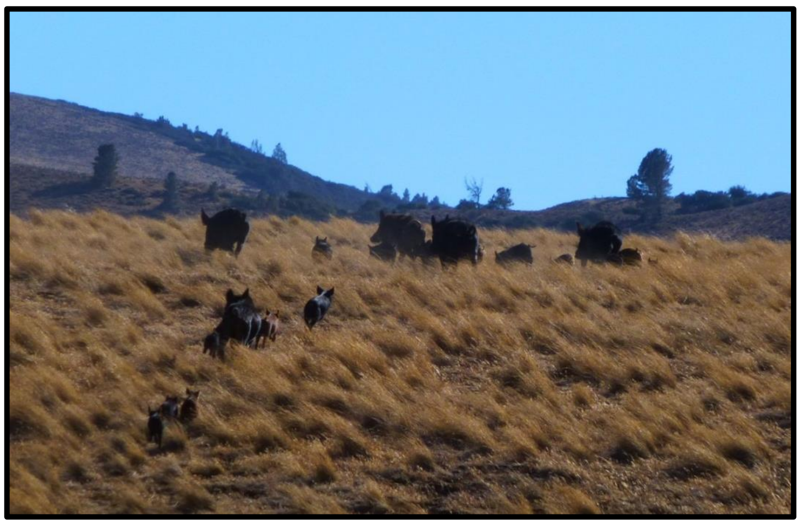

**Figure 5 Wild pig sounder on Tejon Ranch (Photo: I. McCullough, 2013)**

Wild pig populations are difficult to control in part due to their high fecundity and early sexual maturation. Female sows can reach reproductive capability between 4 and 9 months, and in California, the average age is 6 months (Duncan, 1974, (Sweeney & Sweeney, 1982). They are capable of reproducing year round , with peak farrowing periods in July and November (Sweeney & Sweeney, 1982). Under favorable environmental conditions, sows can produce two litters of three to eight piglets in a single year, and litters of more than 10 are possible (Figure 5, Figure 6) (Reginald H. Barrett, 1978). As a result of these biological characteristics, their growth rates can be exponential. Typical growth rates are 40% or higher, and some European boar populations have been as high as 178% (B. Coblentz & Bouska, 2007). This gives wild pigs the ability to recover quickly from the effects of management programs or other natural environmental restraints, such as droughts. A model of wild pig populations is discussed further in Appendix 3: Wild Pig Population Model.

**Figure 6 Wild pig sounder on Sedgwick UC Natural Reserve (Photo Credit: Sedgwick UC Natural Reserve, 2013)**

## 3.2 Foraging Behavior

Wild pigs are efficient foragers. They can change food preference based on availability, and can exploit a food source in a short period of time, including acorns, riparian reptiles and amphibians, or agricultural crops. Wild pigs are known to consume animal material, however the majority of their diet is plant based (Baber & Coblentz, 1987, Schley & Roper, 2003). Studies of wild pigs in the U.S. have shown that pigs preferentially target mast, fresh shoots and herbs, and roots over other food sources. Wild pigs on Santa Cruz Island were shown to consume acorn mast for 70 % - 100% of their diet when it was available (B. Coblentz & Bouska, 2007). Wild pig farrowing success is closely linked to forage quality and availability. One study found that sows with access to irrigated pasture when other forage was limited were capable of producing 20% more fetuses than sows that did not have access to the higher quality forage (Reginald H. Barrett, 1978).

## 3.3 Preferred Habitat

Wild pigs are habitat generalists, although seasonal variations in habitat use by wild pigs are observed. Preferable habitats for pigs include oak woodlands, mixed-conifer forests, oak grasslands, and chaparral shrublands (B. Coblentz & Bouska, 2007) as well as riparian and wetland areas. Wild pigs can also be found in grassland and rangeland areas, however these are less protected from predators.

Sweitzer and McCann (2007) found that wild pigs were most abundant in oak-dominated habitats in California's Central and North Coast areas. In particular, the distribution of wild pigs was closely linked to parts of six provinces or ecoregions where eight native oak species and annual grasslands (also known as oak woodlands) offer cover and forage to pigs (Figure 7). As the authors noted, oak woodlands in California provide numerous benefits including watershed protection, public recreation and habitat and forage for over 3500 species of vertebrates and invertebrates (Rick A. Sweitzer; Blake E. McCann, 2007, Garrison & Standiford, 1996). California's oak woodlands have also been counted as one of the Earth's 25 biodiversity hotspots (Myers, Mittermeier, Mittermeier, Da Fonseca, & Kent, 2000).

It is important to note that these ecologically important areas have also been particularly vulnerable to agricultural and urban development pressures on them as well as recent outbreaks of disease. For these reasons, the damaging effects caused by wild pig presence and activity poses an additional threat to an already stressed system.

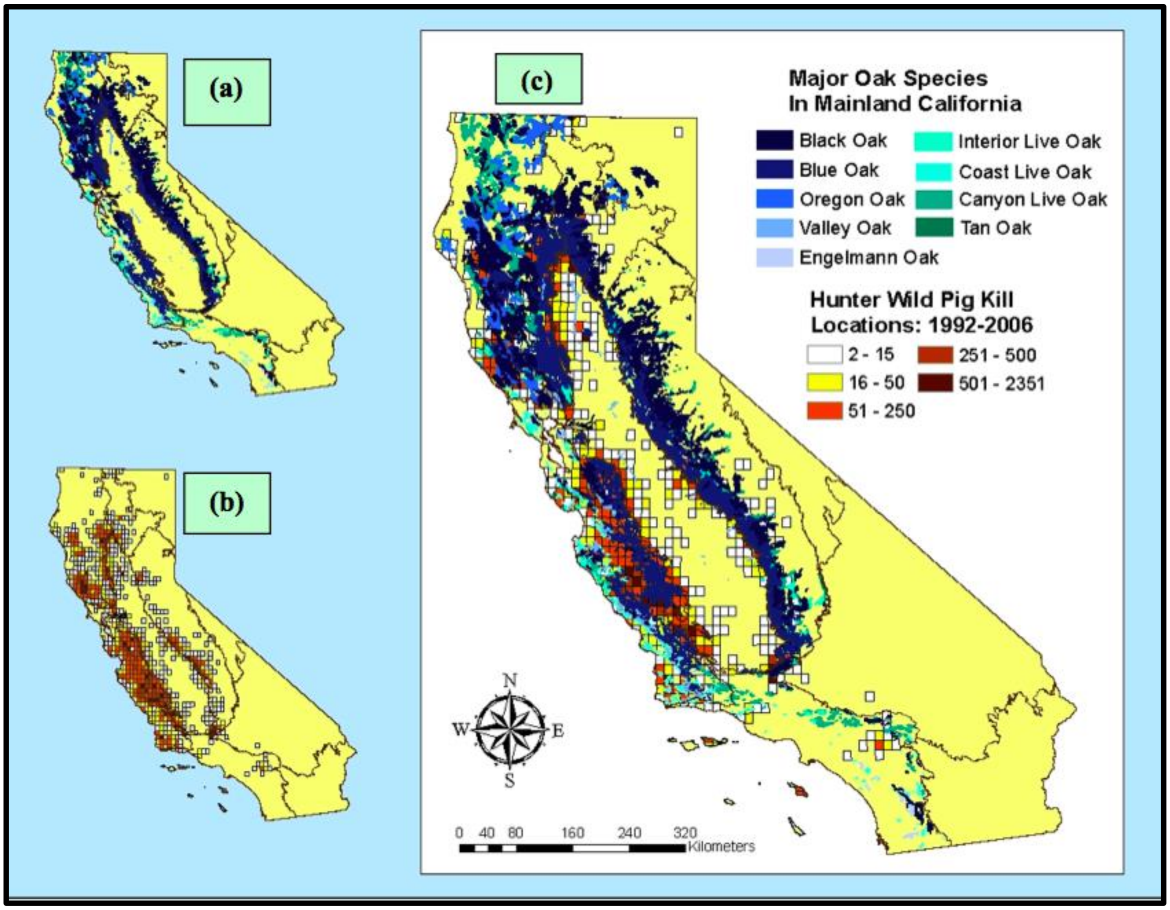


**Figure 7 Overlap between oak species and where wild pigs are found in California (Sweitzer and McCann, 2007)**

## 3.4 Wild Pig Social Behavior and Home Range

Sows typically travel with other sows and juveniles in groups called sounders, while boars are typically solitary except when breeding (Richard A. Sweitzer et al., 2000). Pigs exhibit a home range behavior, and estimates of home range vary between sexes, subspecies, and season, based on temperature, water, and forage availability. Several studies have estimated the home range size of wild pigs in California to be between 2.3 -7.5 $km^2$ with an average of 2.5 $km^2$ (Richard A. Sweitzer et al., 2000). In general, females tend to have smaller home ranges compared to males, and the average home range of male boars in California is 7.48 $km^2$, while an average of 6.85 $km^2$ has been found for other areas (Richard A. Sweitzer et al., 2000).

Wild pig home ranges are characterized by core areas crisscrossed with a network of paths. Density estimates, which are dependent on forage availability and hunting pressure, range from 0.7 pigs/$km^2$ in 1994 to 3.8 pigs/$km^2$ in 1995 in California, due to the fact that 1995 experienced higher rainfall and increased forage (Richard A. Sweitzer et al., 2000). Assuming the California average of 2 pigs/$km^2$, Tejon Ranch is estimated to have approximately 2,000 pigs. However, wild pig densities can change significantly, both spatially and temporally depending on factors including habitat composition, density of populations after farrowing, and hunting management (Massei, Genov, & Staines, 1996). Sweitzer also reported lower densities of pig in areas of moderate to high hunting pressure as compared to areas with no or little hunting (Richard A. Sweitzer et al., 2000).

# 3.5 Wild Pig Invasion

Invasion rates can vary, and most invasions tend to occur irregularly, driven in part by resource availability (Singer, 1981). During a time of drought in California, wild pigs' range was constricted, but following the drought's end, the range of the population moved back into areas that had been previously occupied (Thus, it can be expected that in times of drought or low food resources that wild pigs on Tejon would necessarily restrict their ranges. It should be noted that when environmental conditions became favorable again, wild pig ranges on the Ranch would be expected to increase again. Additionally, it is estimated that wild pigs have enlarged their home ranges by 5-8 $km^2$ per year in the oak woodlands of California's Sierra foothills (Reginald H. Barrett, 1978, Coblentz & Bouska, 2007).

# 3.6 Wild Pig Predators

Common wild pig predators found in California include golden eagles (*Aquila chrysaetos*), black bears (*Ursus americanus*), mountain lions (*Puma concolor*), coyotes (*Canis latrans*), and bobcats (*Lynx rufus*) (USDA APHIS Wildlife Services New Mexico, 2010). Although black bears and mountain lions are capable of harvesting full grown wild pigs, they are more likely to focus their efforts on piglets rather than adults. All of these species inhabit Tejon Ranch, although their effects on pig populations are unknown. Given the increase in pigs across the state, it seems that there is no top down control for wild pigs.

## Conclusion

Wild pigs affect the landscape in a variety of ways through their foraging habits, direct consumption, and sheer numbers. Characteristics of their biology have allowed them to be successful invaders of many different habitats across the state and on Tejon Ranch. It is important to consider the rapid population growth, intelligence, and generalist nature of wild pigs when evaluating management strategies.

# CHAPTER 4: ENVIRONMENTAL AND ECONOMIC IMPACTS

## 4.1 ECOLOGICAL IMPACTS

### 4.1.1 Negative Impacts

**Figure 8 Wild pig rooting damage on Sedgwick UC Natural Reserve (Photo Credit: Sedgwick UC Natural Reserve, 2013).**

Wild pigs negatively affect other wildlife in three main ways: direct predation, competition for food and habitat, and destruction of habitat. Feral pigs are omnivores and will consume the eggs of ground-nesting birds, amphibians, and reptiles (Merton, 1977, Jolley et al., 2010). Studies have documented them preying on small mammals, amphibians, reptiles, fish, deer fawns, new-born calves, and invertebrates (Seward, VerCauteren, Witmer, & Engeman, 2004). Pigs affect oaks through predation on acorns and uprooting of seedlings (Rick A. Sweitzer & Van Vuren, 2002), thereby creating indirect effects on other species that prey on acorns and seedlings. Acorns are recognized to be one of the most important food sources for wildlife species throughout California and the decline of acorns has been linked to numerous declines in wildlife species.

Acorn consumption by feral pigs has been extensively documented, and it has been estimated that one adult feral pig can consume up to 1300lbs of mast per year (B. E. Coblentz, 1990). Still other food habit studies indicate significant predation by pigs on gophers, voles, and California ground squirrels, all of which are predators on acorns and oak seedlings (Loggins, Wilcox, Van Vuren, & Sweizter, 2002),

As wild pigs root deeper into the ground (Figure 8), increasingly more plant roots or rhizomes are exposed to the atmosphere; this leads to reduced plant growth and increased plant mortality (Bratton, 1975). Exposed roots also increase the probability of mortality, either from exposure or because of subsequent herbivory by hogs or other animals upon those exposed roots. In addition, feral hog uprooting of debris and leaf litter, even at low to moderate intensities, may adversely affect the native ecological processes of the ecosystem (Figure 9) (Kastdalen, 1982), (Lacki & Lancia, 1986). Plant debris and leaf litter on the ground surface serve as protective cover for small vertebrates and invertebrates, and the litter and debris also aid in the regeneration and succession of various plant species.

Figure 9 Wild pig rooting damage on Tejon Ranch (Photo: I. McCullough, 2013).

Tierney and Cushman (Tierney & Cushman, 2006) have shown that native and exotic plants from different functional groups vary greatly in their recovery from pig disturbance. Exotic taxa were generally able to rapidly colonize and persist in pig disturbances, whereas native taxa usually exhibited a slow but steady rebound following pig disturbance. They suggested that the health of coastal California grasslands may be enhanced substantially by eliminating or greatly reducing the size of feral pig populations.

Due to their disruptive foraging and aggressive nature, feral pigs can also displace or prey on other wildlife. Studies have examined the overlap between wild pigs and white-tailed deer in term of food resource (Springer, 1977, Wood & Barrett, 1979, Yarrow & Kroll, 1989, R. B. Taylor & Hellgren, 1997). Yarrow and Kroll (1989) raised the possibility that in years of low mast availability deer populations could be affected by competition with wild pigs for food (e.g. acorns). Other studies, however, failed to detect important dietary overlap between wild pigs and white-tailed deer (R. B. Taylor & Hellgren, 1997), and more research to understand the impacts of pigs on other game species. Anecdotally, here have been reduced white-tailed deer sighting by hunters in areas with feral pigs in New York (USDA, 2013), and such disruptions are possible on the Ranch although none have been documented. Other impacts on wildlife include direct predation on a number of invertebrates including earthworms, leeches, grasshoppers, centipedes, beetles and other arthropods as well as salamanders, frogs, fish, crabs, snakes, turtles, rodents, muskrats, and eggs and chicks of ground-nesting birds

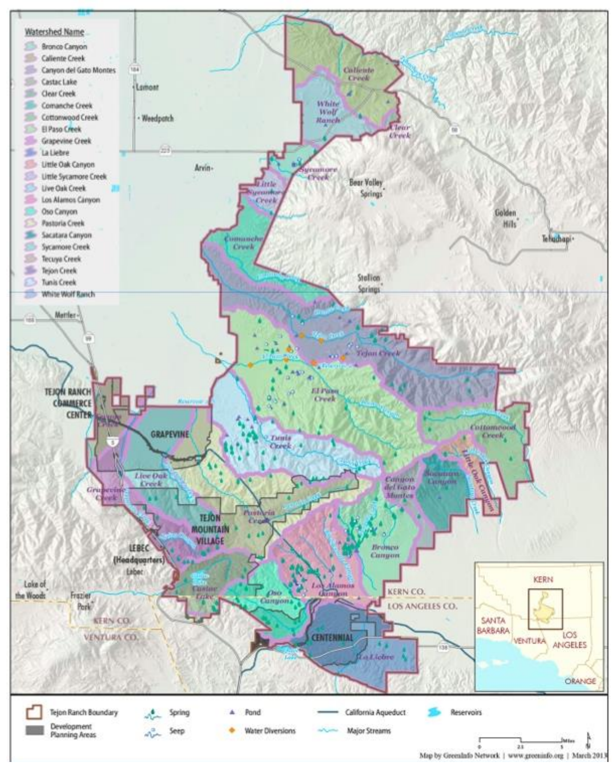


Figure 10 Tejon Ranch Watersheds, showing major water sources including streams, springs, lakes, reservoirs, and stream diversion points (RWMP, 2013)

Feral pigs can also stress sensitive plant and animal species through habitat disturbance caused by rooting (Jolley et al., 2010), particularly in riparian areas. The US EPA estimates that one feral pig can destroy up to 10 acres of wetlands in its lifetime (Richard M. Engeman et al., 2007). Tejon Ranch contains numerous fragile wetland systems (Figure 10), and the literature suggests that the feral pig populations are causing significant damage to sensitive ecosystems such as these.

In California's Pinnacles National Monument, just 200 miles away, there was great concern over the degree to which feral pigs negatively impacted limited wetland areas. Impacted species included the threatened California red-legged frog

(*Rana aurora*) and California tiger salamander (*Ambystoma californiense*) (McCann & Garcelon, 2008). In a Louisiana study, dense pig populations were associated with decreased water quality, particularly in the form of increased fecal coliforms (Kaller, Hudson III, Achberger, & Kelso, 2007).

Wild pigs lack sweat glands and must regulate their body temperature in other ways. As a result, they use a number of behavioral mechanisms to regulate body temperatures, and they prefer areas with easily accessible water, quality forage, and ample amounts of cover, especially during the summer months (Baber & Coblentz, 1987). They create wallows in riparian areas to cool themselves during periods of high temperatures. After wallowing, pigs will rub against trees leaving the appropriately named "rubs." Damage to sensitive riparian habitats due to wild pig wallowing and rooting has been observed on the Ranch. There may also be direct predation of special status species such as the Foothill Yellow-Legged Frog (*Rana boylii*), California Red-Legged Frog (*Rana draytonii*), Yellow-blotched Ensatina (*Ensatina eschscholtzii croceator*), Tehachapi Slender Salamander (*Batrachoseps stebbinsi*), and San Diego Blainville's Horned Lizard (*Phrynosoma blainvillii*) (Tejon Ranch Conservancy RWMP, 2013). Decreased water quality related to bacterial contamination and erosion from wild pig rooting, wallowing activities, and cattle grazing has also been observed in riparian zones on the Ranch.

Besides wallows and rubs, other evidence of wild pigs includes scat, hair, tracks, rooting, resting beds, and farrowing nests. Both resting beds and farrowing nests resemble large bird nests on the ground, but the bottom of farrowing nests has been rooted out more and made deeper. The discovery of these types of farrowing beds in an area on Tejon Ranch would indicate that reproduction is occurring nearby.

There are important adverse impacts that are likely occurring on Tejon Ranch. Evidence of their rooting activity has been observed in most of the oak woodlands on the property, and it is likely, based on studies of pig diets elsewhere in the California, that pigs consume large numbers of acorns when they fall to the ground in the fall (B. E. Coblentz, 1990). Blue, valley, and black oak woodlands support diverse wildlife communities on the Ranch, and cavity-nesting bird species such as acorn woodpecker, violet-green swallow, oak titmouse, and western bluebird are abundant on the property. It is likely that wild pigs directly affect mule deer due to competition for acorns. It is also possible that wild pig predation may adversely affect ground-dwelling and ground-nesting wildlife species, and that long-term livestock grazing and feral pig rooting may also reduce the diversity of the oak understory plant community. Cavity-nesting birds and mule deer, understory plant communities, and the oaks themselves are all conservation targets for the Tejon Ranch Conservancy (Tejon Ranch Conservancy RWMP, 2013)

### 4.1.2 Beneficial Impacts

There is little evidence in the literature about positive effects of feral pigs on their habitat. At Tejon, pig carcasses potentially serve as an important food source to sensitive scavenging animals such as the California condor (*Gymnogyps californianus*). They may also be an important food source for the large numbers of golden eagles that are documented on the Ranch. Golden eagles are known to predate piglets and increases in eagle population size have been attributed to increased pig populations in other parts of the state (Roemer, Donlan, & Courchamp 2002). Finally, large predators such as mountain lions have been known to predate pigs in other locations (Harveson, Tewes, Silvy, & Rutledge, 2002).

## 4.2 Economic Impacts

### 4.2.1 Statewide Economic Benefits

Hunting wild pigs has become an important component of game management in the state of California. More than 94,500 wild pigs were harvested in the state between 1993 and 2010, according to harvest tags returned to CDFW. While 1999 and 2002 were years of high harvests, the state has seen a decline in the number of wild pigs harvested since 2002 (Figure 11). A 1991 law requiring hunters to purchase booklets of five, rather than individual, tags seemed to be a step towards greater control of pig populations. However, that regulation has since been rescinded, and hunters must currently purchase individual tags. Hunters may purchase an unlimited number of tags. Each resident wild pig tag costs $21.86 and resident hunting licenses cost $45.93. These fees are higher for non-California residents (CDFW, 2013). In-state hunters come from across the state, and there are a high number of pig tag sales in the vicinity of Tejon Ranch (Figure 12).

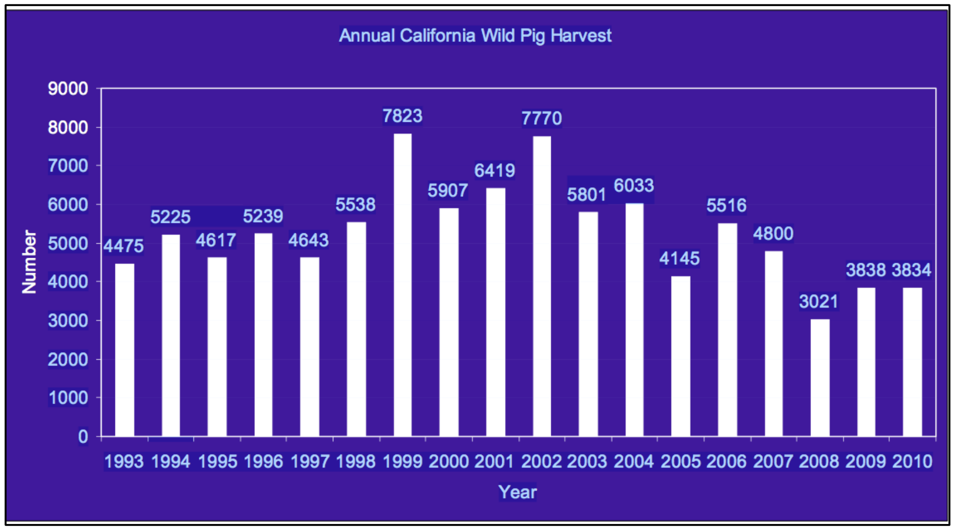


**Figure 11 Annual pig harvest in California between 1993 and 2010 (CDFW, 2013).**

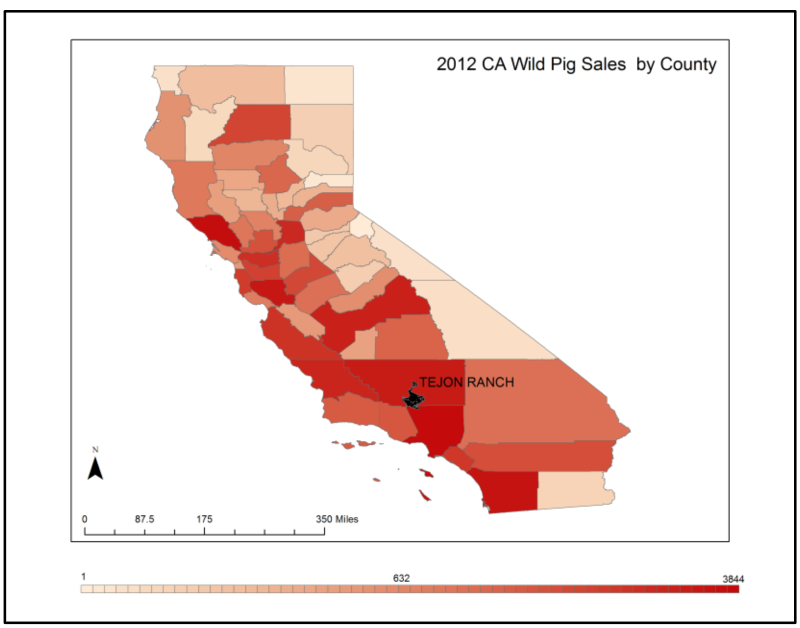


**Figure 12 Numbers of wild pig tags sold by county in 2012, darker shading indicated more tags sold. (CDFW, 2012)**

The sale of these tags is popular enough that revenue from wild pig tags now accounts for over $1 million in annual revenue for CDFW, and the number of pig tags sold in the state is now roughly 60,000 per year (Figure 13 and Figure 14, respectively). The state of California has a financial incentive to maintain the listing of wild pigs as game animals. Revenue generated by the sale of pig hunting tags is collected in the general fund and currently makes up about 4.5% of CDFW's total hunting revenue of approximately $24.5 million (Figure 15).

Interviews with the CDFW confirm that the agency sees pigs as an important big game species in the southern part of the state, and the agency sees value in maintaining the big game classification  to provide recreational hunting opportunities for hunters(King, Evan, 2013). Furthermore, overall hunting has declined in the state during the last decade, driven largely by the decline in deer tag sales, while pig hunting, or at least the number of pig tags sold, has continued to increase slightly (Figure 16).

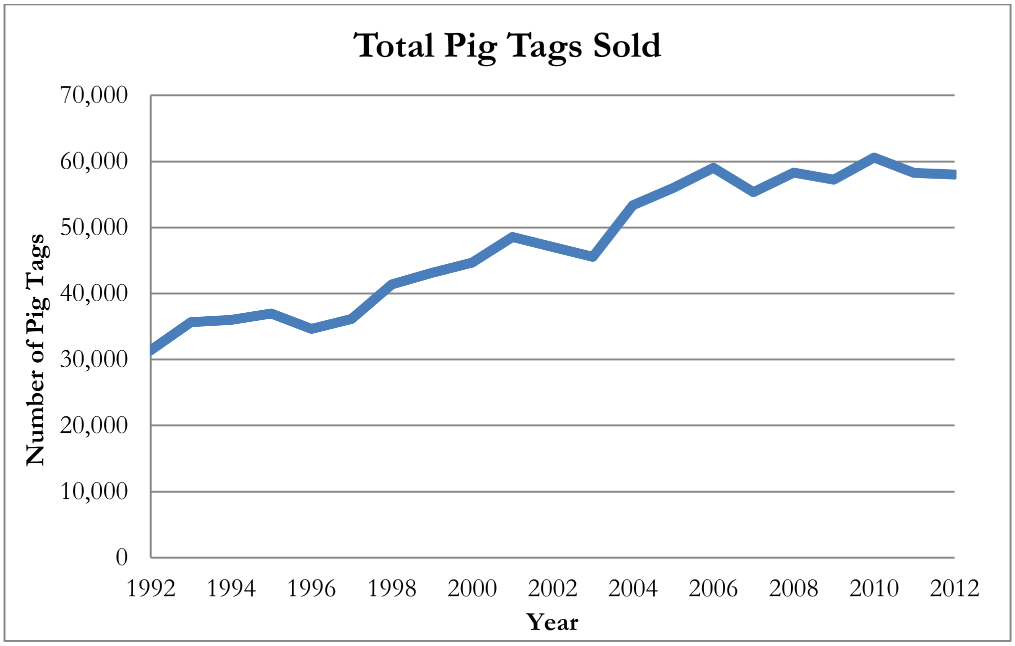


**Figure 13 Number of wild pig tags sold in California between 1992 and 2012 (CDFW, 2013)**

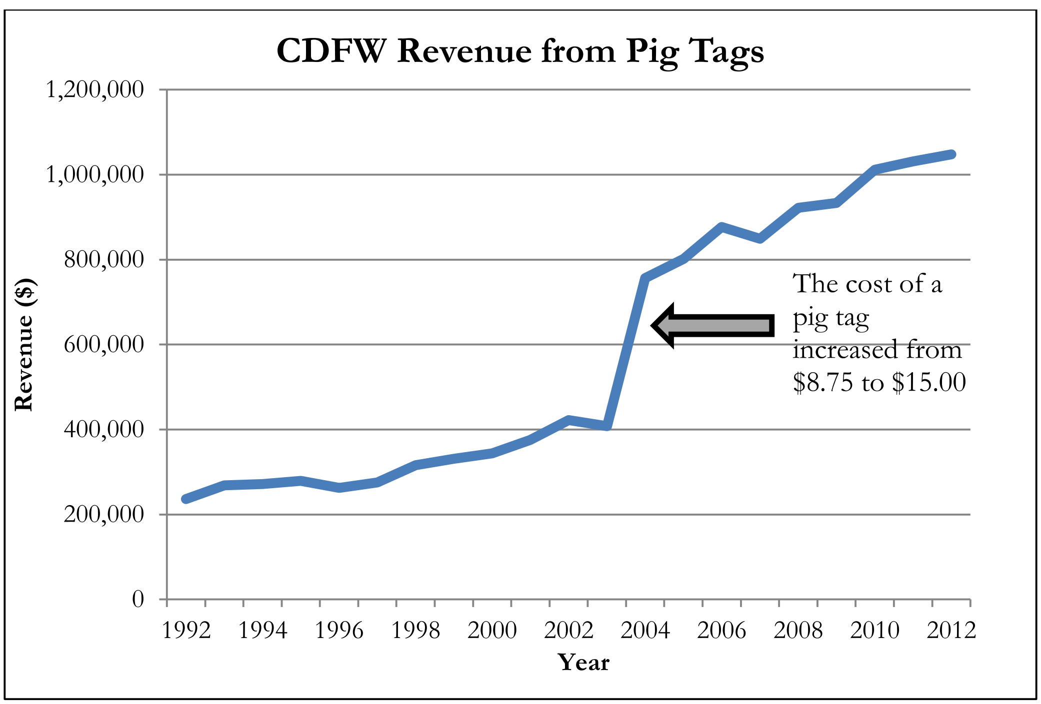


**Figure 14 Revenue for California between 1992 and 2012. The gray arrow indicates an area of abnormally steep slope, representing an increase in the price of pig tags from $8.75 to $15.00 (CDFW, 2013)**

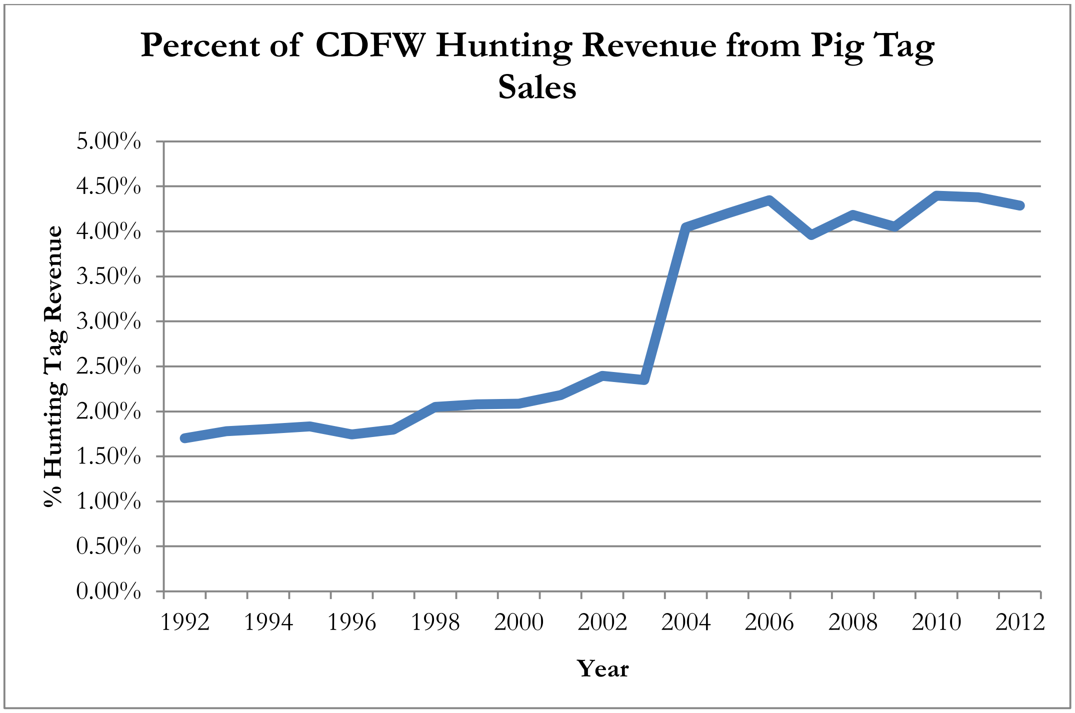


**Figure 15 Percent of CDFW revenue from wild pig tag sales. We see an increasing trend over time, suggesting that pig tag revenue is increasing in importance for agency funding. (CDFW, 2013)**

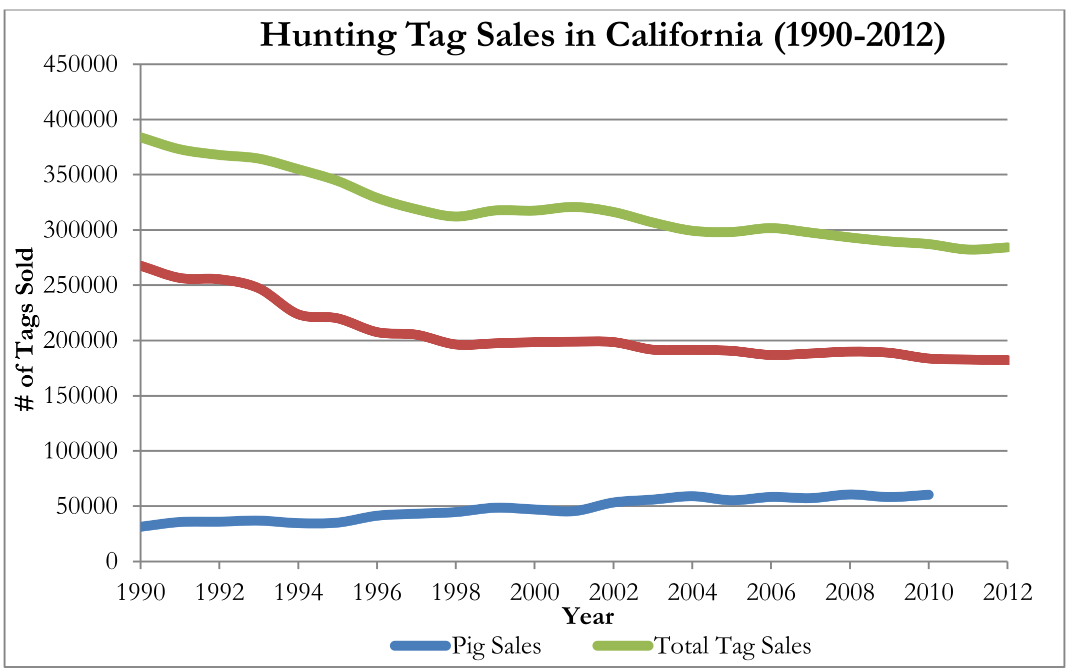


**Figure 16 Hunting tag sale trends in California between 1990 and 2012. Decreased hunting in California is believed to be largely driven by the decline in deer tag sales. It is interesting to note that the number of pig tags sold has increased over time. (CDFW, 2013)**

## 4.2.2 TEJON RANCH ECONOMIC BENEFITS

In addition to CDFW, there are a number of other groups in the state that reap economic benefits from the hunting of feral pigs. Various private landowners, including the Tejon Ranch Company, operate commercial hunting programs, which provide important sources of revenue. Additionally, there are associated economic benefits to hunting guides, lodging, gas stations, and hunting supply stores throughout the state.

Currently there is not an explicit control program for managing wild pig populations on Tejon Ranch. The primary method of wild pig take is through a paid recreational hunting program. However, the primary target of this program is not to control populations. The hunting program is a source of revenue for the Tejon Ranch Company, and pigs make up a large percentage of hunted game on the Ranch. Estimated revenue from pig hunting for the Tejon Ranch Company was roughly $1.2 million, averaged annually between 2001 and 2008. This estimate is based the harvest data discussed above, which included membership hunts, guided hunts, and unguided wild pig management hunts.

With the exception of wild pigs, Tejon Ranch manages hunted game under a license through the CDFW Private Lands Management (PLM) Program. The program is meant to "offer landowners incentives to manage their lands for the benefit of wildlife" (CDFW, 2013). With their PLM license, the Ranch sets hunting seasons (within the state's own seasons), harvest limits, ages of animals to be harvested, and the number of hunting licenses issued. Tejon Ranch is also a participant of the SHARE Program, which incentivizes private landowners by offering full liability coverage and potential financial compensation to allow controlled public hunting for specific time periods on their property. Public participants enter in a random drawing for access permits through CDFW. Successful applicants of the SHARE Program drawing are provided access to Tejon Ranch on select weekends throughout the year in the WPMHs.

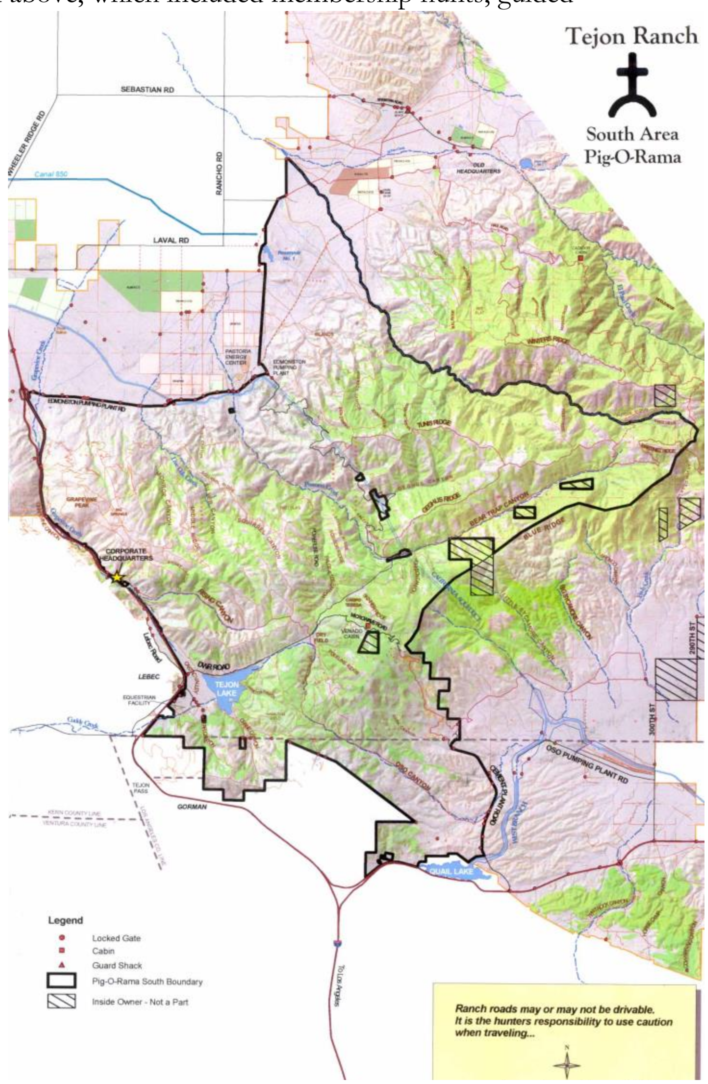


**Figure 17 Map of the south hunting area of Tejon Ranch**

According to Ranch management, the pig hunting program is in a state of development and hunting efforts for pigs have been ramping up in the past year. Tejon Ranch's Vice President of Ranch Operations stated that the Ranch's current management goal is "to continue to hunt as many pigs as possible," and that their target is approximately 1200 pigs per year (B. Grant, Personal Communication). This is the most intensive harvest of pigs on the Ranch to date, with 1193 wild pigs harvested in the 2012-2013 hunting season (Tejon Ranch Harvest Records, 2013).

There are several types of pig hunts available at the Ranch: Guided Pig Hunts and Wild Pig Management Hunts (WPMH, 2013). Guided pig hunts cost between $1100-1200 per hunter; Wild Pig Management Hunts, which are unguided, cost $500 per hunter. Guided Pig Hunts are usually group hunts lead by a guide on the Ranch's different hunting areas (Figure 17). Wild Pig Management Hunts are the only hunt offered at Tejon that does not require a membership. The Ranch offers WPMHs over two weekends of the year, however this program may be terminated in the near future.

Figure 18 illustrates wild pig harvest levels on the Tejon Ranch and shows the variability in harvest since 2001. Prior to the 2013 harvest season, harvest numbers peaked at 937 in 2003 and then declined to 425 and 160 in 2005 and 2010, respectively. It remains unclear whether the harvest decline was due to a decline in overall pig abundances, or from hunter effort (Tejon Ranch Conservancy RWMP, 2013). There was a temporary hunting closure in place on Tejon Ranch during the 2011-2012 hunting season that likely led to a decline in harvest numbers. Currently, approximately 700 pig hunts occur on the Ranch every year; approximately 500 of these hunts are guided, while the remainders are part of the unguided hunts through the Wild Pig Management Hunt program. During these hunts, 80-90% of hunters target pigs specifically, while the remainder target multiple species, including pigs (Personal Communication, B. Grant).

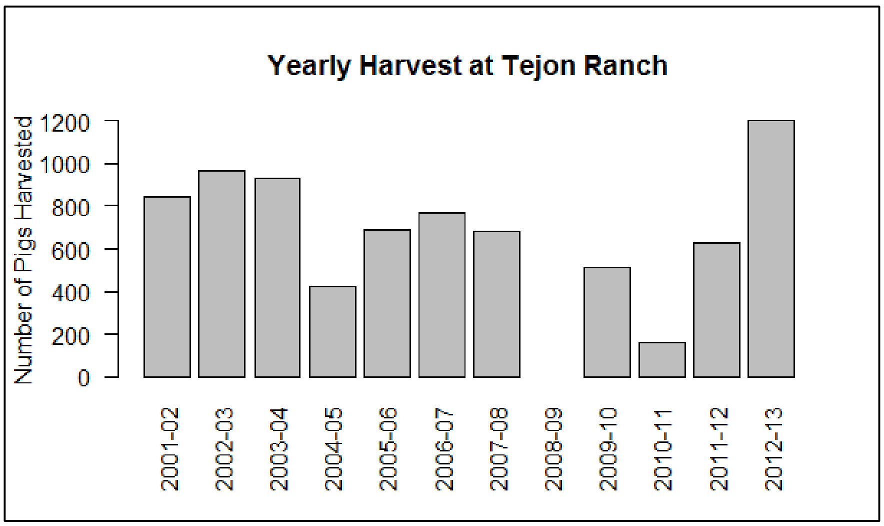


**Figure 18 Preliminary Tejon Ranch Company harvest data from 2001-02 through the 2012-13 hunting season. Data for the 2009-09 season was not obtained, and therefore omitted from this figure. Data from all hunt types are included here. (TRC Harvest Data, 2013)**

Pig harvest on Tejon Ranch varies seasonally as well as between years. Harvests tend to decline during the fall months, which is believed to be due, in part, to hunters prioritizing deer harvest in fall (Figure 19). Additionally, the Ranch reduces hunting significantly in August, which is known to be hot and dry on the Ranch. In years of normal rainfall, optimal months for hunting wild pigs in California are November through May, when temperatures are more amenable for both hunters and pigs. Pigs also become more diurnal during this period and are in better condition due to the wide availability of water and food sources (Reginald H. Barrett, 1978).

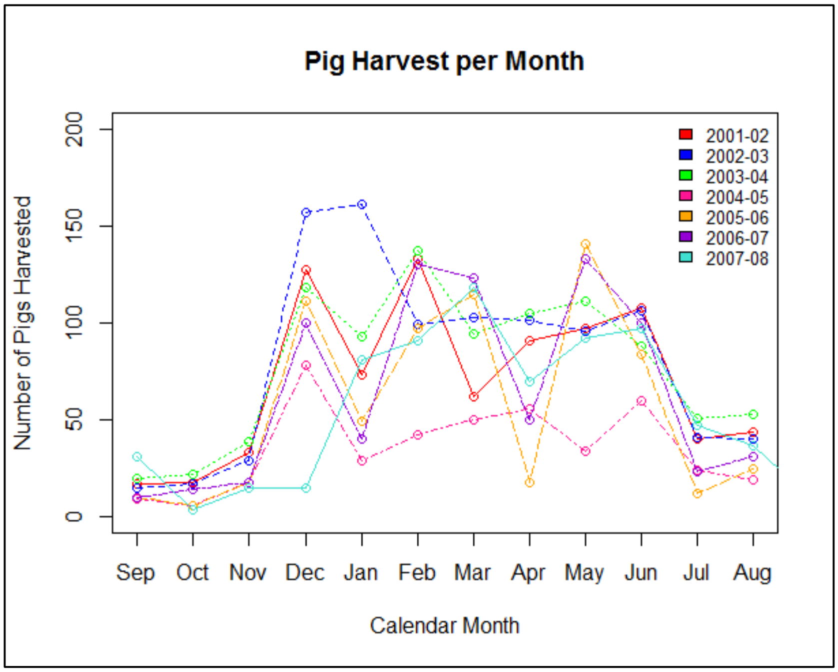


**Figure 19 Preliminary Tejon Ranch Company harvest data from 2001 to 2008 by month. Data from all wild pig hunt types are included here. (TRC Harvest Data, 2013)**

### 4.2.3 NATIONWIDE, STATEWIDE, AND TEJON RANCH COSTS OF WILD PIGS

Still, there are costs associated with wild pig damage and control measures taken by landowners across the country and California. Estimates for damage incurred by pigs tend to vary widely across different sources of literature and no conclusive studies have been performed to date to track the amount of damage incurred by landowners in California. Limited California survey estimates put the low end of pig damage to crops at $1.2 million in 2006 and $11.3 million to natural areas between 2005--2007 (Rick A. Sweitzer; Blake E. McCann, 2007)). USDA Wildlife Services tracks the amount of damage reported on lands that they respond to. They recorded roughly $28 million in damages in California last year caused by damage to agriculture, rangeland, and developed land. Tejon Ranch leases portions of its land for agriculture and ranching and also has its own farming operation. As such, wild pig damage to these operations should be a concern for Ranch management.

#### *AGRICULTURAL AND RANGELAND DAMAGE*

Wild pigs most commonly damage agriculture through their rooting activities and through the direct consumption of agricultural products (Barrett and Birmingham 1994). Studies have shown that in less than a week, a single group of wild pigs can destroy a 10-acre cornfield (Gates 2012). Damage effects can also include wasted fertilizer, tractor, and operator time (Mengak 2012). Such indirect losses from wild pigs can be difficult to measure but are nonetheless important. Grape growers in Texas and California have reported pigs damaging vines and uprooting plants (Kane 2010, McCoy 2012). It is important to note that pig damage to vineyards can occur rapidly. For example, in the Hérault area of southern France, compensation paid to vineyards for damage by wild pigs increased from $31,352 (U.S.) in 1990-1992 to $700,890 in 1993 (Calenge et al. 2004).

Nationwide, wild pigs are estimated to be causing at least $1.5 billion in damages and control costs, based on crop damages and control costs of about $300 per pig annually (Pimental, 2007). The state of Georgia estimates that wild pigs caused over $57 million in crop and crop related damage within its boundaries in 2011 alone (Mengak 2012). Texas estimates wild pigs annually cause $52 million in damage from destroyed crops, damaged levees and fences, predation, and decreased forage for livestock and wildlife. Landowners in New Mexico estimate that they spend around $7 million per year recovering from damage and attempting to control wild pig populations (Feral Hog Biology, Impacts, and Eradication Techniques USDA APHIS Wildlife Services New Mexico 2010). In California, economic losses to 40 surveyed counties for one year of rooting related damage was estimated at $1.73 million (Frederick 1998).

Wild pigs have long been known to impact rangelands and cattle operations (Beach 1993, Barret and Birmingham 1994). There are numerous documented cases of wild pigs killing lambs and calves in Australia (Choquenot, Kilgour, & Lukins, 1993; Fleming, 2001). Pigs in Texas and California were reported to have killed 1473 sheep, goats, and exotic games animals in 1991 (Barrett and Birmingham 1994). Recent reports to the University of California's Cooperative Extension in Kern, Tulare and Kings Counties state that wild pigs are beginning to kill calves in Kern County as well (Julie Finzel 2013).

Wild pigs have been known to damage fourteen of California's top 20 commodity crops (Table 1), and they are thought to be able to damage the remaining six (California Agricultural Statistics Review 2012-2013, Pesk Risk Assessment for Feral Pigs in Oregon). On Tejon, 6,000 acres are devoted to pistachios, almonds, alfalfa, and wine grapes, all of which have been damaged by pigs in other parts of California or the country. Wild pigs also threaten the 250,000 acres covered under the cattle leases through the types of pasture and livestock damage discussed above.

**Table 1 Top 20 Commodities in California for 2011**

| Agricultural Commodities | Total Value ($) | Agricultural Commodities | Total Value ($) |
|---|---|---|---|
| Milk^ | 7,680,566,000 | Flowers & Foliage* | 1,011,530,000 |
| Almonds* | 3,866,800,000 | Cotton Lint^ | 893,952,000 |
| Grapes* | 3,860,351,000 | Pistachio* | 879,120,000 |
| Cattle & Calves* | 2,825,125,000 | Rice* | 774,432,000 |
| Nursery plants* | 2,683,100,000 | Chickens* | 702,051,000 |
| Berries, * | 1,948,118,000 | Broccoli* | 684,033,000 |
| Hay* | 1,734,660,000 | Carrots* | 659,610,000 |
| Lettuce* | 1,513,023,000 | Oranges^ | 656,388,000 |
| Walnuts* | 1,323,070,000 | Avocados* | 460,560,000 |
| Tomatoes^ | 1,264,936,000 | Eggs, Chicken^ | 391,578,000 |

***Commodities that have been damaged by feral pigs in other regions**
**^Commodities that could be damaged by feral pigs**
**Source: California Agricultural Statistics Review 2012-2013. Adapted from the Pesk Risk Assessment for Feral Pigs in Oregon**

## *Developed Land Damage*

Wild pigs can rapidly destroy sod when rooting for food in locales such as lawns, sports fields, parks, and golf courses. This behavior leads to unsightly, erosive areas, and repairing this type of damage can be expensive. States with growing wild pig populations are increasingly encountering these types of property damage (Higginbotham 2012). This effect may become more relevant as portions of the Ranch are developed, particularly the Tejon Mountain Village.

## *Natural Resource Costs*

It is even more difficult to estimate the costs of ecological damage from wild pig activity. In 2006 and 2007, Sweitzer and McCann (McCann, 2007) administered a survey to managers of all identifiable natural areas in California in order to assess the ecological and monetary costs that accompany managing natural areas in the range of wild pigs. They found that the overall minimum economic costs to all natural area management entities that indicated wild pig-related management costs were $11,300,132 over the previous three years and $18,672,023 overall. The authors, however, noted that even these estimates were conservative because the costs were related to exclusion/removal of wild pigs and did not include any estimate of damage done to the actual natural resources (Rick A. Sweitzer; Blake E. McCann, 2007).


**Figure 20 Wild pig crossing warning sign in Carmel, CA (NYT, 2013)**

Other states have attempted to value wetlands, an area particularly threatened by wild pigs, in economic terms. The authors of the 2012 Feral Pig Management Plan for New York used the public's "willingness to pay" (i.e., the amount of money people are willing to spend to restore different types of wetlands) in order to place a monetary value on acres of wetlands damaged by wild pigs (USDA, 2013). Using methods similar to Engeman et al. (2007), Wildlife Services in New York estimated the monetary value of their wetlands based on a report to the EPA in 1997 for the northeastern U.S. (King 1998). Because it was not known which freshwater wetland type in New York received the most damage from wild pigs, the lowest "willingness to pay" value per acre was used: the emergent wetlands type. After adjusting for inflation (BLS 2012), a conservative estimate of the value of restoring wetlands lost to wild pig damage in New York was approximately $62,970.10 per acre (Richard M. Engeman et al., 2003). Using the Environmental Protection Agency's estimate of 1 wild pig destroying 10 acres of wetland in its lifetime, the 40 individuals that the Wildlife Service culled from the New York population in 2012 represented a potential $25,188,040 worth of damage to wetlands in the state (USDA, 2013).

## *Impacts of Diseases and Parasites*

Thirty diseases and thirty-seven parasites transmissible to people, domestic animals, and livestock have been documented in wild pigs (Seward et al., 2004), and pigs are susceptible to numerous viral and bacterial diseases (Table 2). Pigs can carry pseudorabies, which threatens the nation's pork industry, bovine tuberculosis, a threat to the nation's cattle industry, and a number of strains of brucellosis, which threaten both domestic pigs and cattle populations. Throughout the country, the USDA is working on eradicating these three diseases. Because wild pigs populations typically grow to dense numbers and interact frequently with livestock populations around water troughs, disease transmission from a given wild pig population to livestock can occur quite easily (Ward, Laffan, & Highfield, 2007). Because Tejon Ranch has an active cattle ranching operation and a significant wild pig population that occupies the same rangelands, wild pigs pose a disease risk to the herds present on the Ranch.

Wild pigs have also been known to transmit diseases to humans. In 2006, wild pigs were identified as a potential source of the Escherichia coli O157:H7 contamination of fresh young spinach that caused in a nationwide outbreak resulting in 205 illnesses and three deaths (Jay et al., 2007). Wild pig meat has also been documented to transmit brucellosis to humans and pig meat has been suspected as the source of various other human ailments (Meng, Lindsay, & Sriranganathan, 2009). Proper care of wild pig meat and cooking the meat thoroughly can eliminate the risk of disease transmission, so concerns from this are generally considered secondary to threats to livestock and human-consumed row crops.

There is significant evidence that, as a whole, wild pig populations can be both vectors and reservoirs of harmful livestock diseases (Meng et al., 2009). Scientists have documented the potential for wild pigs to serve as vectors of disease outbreaks from foreign animal diseases in number of states and have concluded that wild pig populations are a threat that warrants control measures (Cozzens et al., 2010; Deck, 2006; Pineda-Krch, O'Brien, Thunes, & Carpenter, 2010). Indeed, numerous disease outbreaks in the past have been traced back to wild pigs. In 1965, for example, wild pigs transmitted bovine tuberculosis to beef cattle (Barrett and Birmingham 1994). The expansion of pigs throughout California since that time has been raised as a serious concern by epidemiologists. Previous foot and mouth outbreaks in California in the 1920s proved quite difficult to contain because of deer populations, and wild pig populations were not yet sufficient in the state to play a role in disease transmission (Ward et al., 2007). Pigs are a much more effective vector for disease transmission than deer and the current extent of pigs would make containing such an outbreak exponentially more challenging. In essence, pig populations that interact between cattle herds serve as links across which diseases may pass. Given the high degree of connectivity of the pig populations throughout the state of California, there is a high potential for an outbreak to spread quickly.

Brucellosis refers to a highly contagious family of diseases that can cause livestock populations to abort fetuses (Davis, 2014). Wild pigs are the only game species in the state that are considered serious vectors of brucellosis to livestock (Drew, Jessup, Burr, & Franti, 1992). Outbreaks of brucellosis within a cattle herd can be extremely costly and a single, localized outbreak changes an entire state's brucellosis-free status with APHIS. The loss of brucellosis-free status in a state can have dire economic consequences and impact ranchers' ability to export livestock products out of the state and country (Bittner, 2004). Wild pig populations have been documented carriers of brucellosis throughout their distribution in the United States (Zygmont, Nettles, Shotts, Carmen, & Blackburn, 1982) and California populations have tested positive as vectors of the disease (Drew et al., 1992).

Transmission of brucellosis is thought to come primarily through contact with infected placentas, amniotic fluids, vaginal discharges, milk, semen, reproductive tissues, and other organs (Davis, 2014). While the specific presence of some of these factors are currently unknown on Tejon, there is likely to be a high incidence of contact between wild pigs and cattle occupying the rangelands on the Ranch. The degree of overlap between wild pig and cattle ranges, shared water troughs, and the presence of pig entrails left behind by hunters makes the potential for disease transmission quite high.

Other studies have focused on the potential to spread foot and mouth disease via wild pig populations. California has maintained a foot and mouth free status with APHIS since a 1929 outbreak. Economic analysis of a potential outbreak shows that the results could be disastrous and pose a major long-term threat to the livestock industry (Pineda-Krch et al., 2010). The widespread distribution of wild pigs in California could significantly exacerbate any potential outbreaks and make containing the outbreak both costly and difficult. Wild pigs have been identified as key vectors for transmission of the disease and managers have taken steps to model and account for potential outbreaks (Cozzens et al., 2010).

The potential for wild pigs to transmit brucellosis, foot and mouth disease, or other livestock diseases to cattle populations on Tejon Ranch depends on a number of factors such as appearance of the disease, incidence of interaction between wild pig populations and cattle, and connectivity of the Tejon Ranch wild pig population and other surrounding pigs populations (Fleming, 2001). Pigs are highly mobile, thus making them effective agents of disease and parasite transmission, and livestock that share water sources with pigs can be particularly vulnerable (Mason et al. 1998, Witmer et al. 2003). The abundance of water troughs used by livestock and variety of wildlife on the Tejon property makes this concern particularly relevant for this project. Similarly, the presence of pig populations in surrounding lands and the known populations of wild pigs along the Eastern side of the San Joaquin Valley suggest that there is a high degree of connectivity between the Tejon pig population and others in the state. Zeroing in on a precise potential disease transmission rate on Tejon between feral pigs and cattle is possible, but it would require extensive study beyond the scope of this project.

**Table 2 Viral and Bacterial diseases carried by wild pigs**

| Viral Diseases | Bacterial Diseases |
|---|---|
| Bovine Herpes virus | Anthrax |
| Classical Swine Fever (hog cholera) | Brucellosis |
| Coronaviral infections | Erysipelothrix infections |
| Encephalomyocarditis | Helicobacteria |
| Foot-and-mouth disease | Letpospirosis |
| Influenza A | Bovine tuberculosis |
| Louping-ill virus | Pasteurellosis |
| Malignant catarrhal fever | Plague |
| Menangle virus | Salmonellosis |
| Papillomavirus infections | Yersiniosis |
| Parainfluenza virus | |
| Pestvirus infections | |
| Pseudorabies | |
| Rabbit hemorrhagic disease | |

| | |
|---|---|
| Rinderpest | |
| San Miguel sea lion virus | |
| Swinepox | |
| Swine vesicular disease | |
| Vesicular swine virus | |
| Vesicular stomatitis | |

**Source: Feral Swine Action Plan Oregon. (Compiled by Witmer et al. 2003).**

Because wild pigs tend to concentrate their activities near water and riparian habitats, they may also be a nonpoint source of surface water contamination. Wild pigs have been detected shedding Cryptosporidium parvum oocysts and Giardia duodenalis cysts in California, and Atwill et al. (1997) concluded that wild pigs could be a nonpoint source of protozoan contamination of water resources for this reason. According to the authors, there is robust evidence that the Cryptosporidium parvum oocysts are infectious to humans. They also noted that the higher the densities of wild pigs, the greater the chance for contamination (An Assessment of Potential Impacts of Feral Pigs (Sus scrofa) in Southern California 2009).

### *Effects on Land Values*

Studies on the effects of pigs on land values are conspicuously absent from the literature. We have been gathering data to attempt to conduct such a study, but have so far been unable to secure everything we would need. In an attempt to understand the specific costs to landowners that are relevant to Tejon Ranch, we interviewed real estate agents about the effects of pig damage on real estate prices. Agents suggested that the threat of pig damage could reduce residential and rangeland real estate prices by as much as 5%, however the sample size for this feedback was very small was mostly qualitative in description (Cutler, Carol, 2013; Lein, Jeff, 2013; McDavid, Bill, 2013). Decreases in residential prices were attributed to the impaired aesthetic values of lands impacted by pigs. This is consistent with other studies on the effect of landscaping on housing values (Des Rosier, Francois, Theriault, Marius, Kestens, Yan, & Villeneuve, Paul, 2002).

## 4.4 Use of Depredation Permits to Control Wild Pig Damage

The CDFW recognizes that pigs are a nuisance species for some landowners, and the agency has worked with them locally to control wild pig populations primarily through issuing depredation permits. Interviews indicate that while the agency feels that it is adequately positioned to control populations on public lands where hunting is permitted, private lands and public lands that prohibit hunting present significant management challenges. While pigs can be controlled on some lands, they move very readily back and forth neighboring lands, where control efforts might be lacking, or non-existent.

The total number of pig depredation permits issued by the CDFW has increased dramatically in the last thirty years (Figure 21), reflecting an increasing demand among the state's landowners for the ability to control pig populations on their properties in ways other than recreational hunting. The use of depredation permits as a control option is discussed in further detail in Chapter 6.

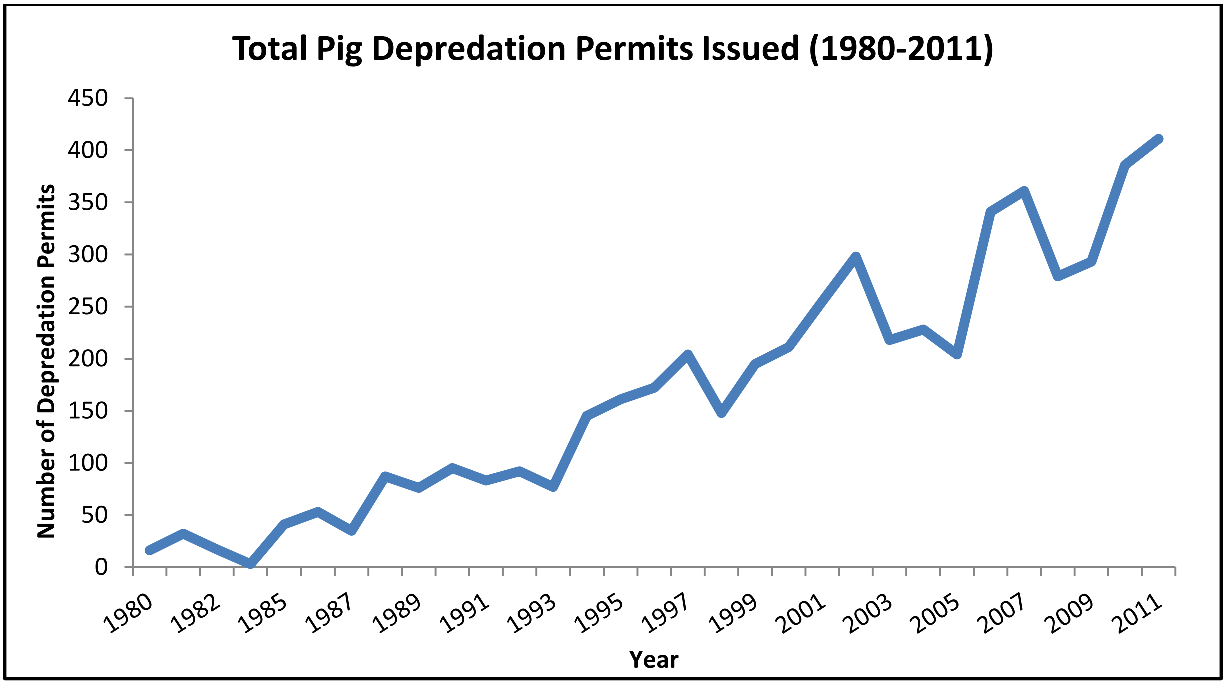


**Figure 21 Total number of depredation permits issued between 1980 and 2011 (CDFW unpublished data)**

## 4.5 Conclusions

Wild pigs are highly destructive species that inflict large amounts of economic and habitat damage throughout the lands that they occupy. Based on other studies of damage and observations on the Ranch, it is assumed that the large wild pig population on Tejon is inflicting serious economic and environmental costs. These costs take the form of physical damage to sensitive habitats, direct competition with (and consumption of) other wildlife, damage to agricultural crops, damage to commercial lands, forage competition with livestock, and increasing the risk of disease transmission for livestock. Given the extent of these risks, it is recommended that Tejon Ranch implement a management program to minimize these risks. Specific management recommendations are discussed in Chapter 7.

# CHAPTER 5: MONITORING WILD PIGS

Successful wildlife management should incorporate strategic monitoring of species of interest. Specifically, management of invasive species requires knowledge about their local abundance and impacts. Most of the current management plans for wild pigs include population monitoring as a crucial component of their management strategy (Engeman et al., 2001). As Engeman states, "If you can't monitor it, you can't manage it."

## 5.1 NEED FOR MONITORING

Despite continued operation of an active wild pig hunting program and growing concern about the negative effects of wild pigs on Tejon Ranch, there is currently no systematic monitoring program in place for wild pigs. Successful habitat preservation and improvement efforts will rely on a robust and efficient program to monitor wild pig abundance and damage to help inform management strategies.

Monitoring pig numbers and activity on Tejon Ranch is important for management in three ways. By documenting the effects of pigs through a monitoring program land managers can strategically implement damage control efforts. Once these control efforts are implemented, monitoring is essential to track the efficacy of the efforts. Finally, monitoring changes in pig population and damage over time will inform future management strategies adaptively. It was our objective to develop a monitoring program that would meet this objectives for the Tejon Ranch Conservancy.

## 5.2 PILOT STUDY GOALS

In order to inform our recommendations for pig monitoring on Tejon Ranch, we conducted a pilot monitoring study on the Ranch in the summer of 2013.

Our goals for this pilot study were to:

1. Identify monitoring methods currently used for wild pig management
2. Test the feasibility of these monitoring methods specifically for Tejon Ranch
3. Evaluate the statistical power and cost effectiveness of these methods
4. Gather initial pig abundance and damage data

We selected monitoring methods based on their ability to meet our objectives for a monitoring program.

## 5.3 DEVELOPING A MONITORING PROGRAM

A variety of methods have been used to monitor wild pig populations and to determine the efficacy of pig control and recovery efforts (Vongkhamheng 2013, Bengsen 2011, Reidy 2011, Gopalaswamy 2012, (Ebert et al., 2012). In a comprehensive review of methods, Engeman (2013) outlines the most desirable qualities of a variety of monitoring methodologies, including practicality, sensitivity, precision, variance estimation, and robustness. Engeman found that indices of abundance rather than absolute abundance estimates are often a more practical means for monitoring wild pigs due to the difficulty and cost of obtaining accurate estimates of wild pig abundance and density (2013).

Indices can provide a reliable metric for monitoring when employed with consistency by detecting changes in the index value relative to indices obtained in past monitoring efforts. This approach represents a significant savings in cost and time when compared with attempts to obtain accurate estimates of population size and density. We used this approach to establish indices of pig abundance (5.3.1 Monitoring Pig Abundance) and pig damage (5.3.2 Monitoring Wild Pig Damage) across five major vegetation types within the Tejon Creek, El Paso Creek, and Cottonwood Creek watersheds on the Ranch from June to August 2013.

As a starting point for informing recommendations for a wild pig monitoring program for the Conservancy we conducted a review of the literature and discussed the potential applicability of established monitoring methods with conservancy staff and expert external advisors. A brief review of available approaches to monitoring wild pigs and the utility of each for Tejon Ranch is provided below.

## 5.3.1 Monitoring Pig Abundance

### *Passive Tracking Index*

A Passive Tracking Index (PTI) is a low-tech method for monitoring pigs that uses pig tracks to establish an index of local abundance. The PTI method places tracking plots throughout the study area in pig travel routes such as dirt roads or game paths. At each plot the number of pig track sets (number of intrusions into the plot) is recorded. The number, frequency, and spatial distribution of these tracks is used to develop an index of pig abundance and pervasiveness.

During the first week of our study we used this method in the field at Tejon Ranch. In order to ground-truth pig track detection success rates we used motion sensing cameras to verify each detection. Detecting tracks presented some difficulty due to the dry conditions on the Ranch in the summer months; loose, dry ground cover made pig tracks hard to distinguish from other markings on the road. Additionally, due to the similarity in track appearance between pigs and other species on the Ranch (e.g. deer), distinguishing tracks between species was time consuming and unreliable. After identifying multiple pig tracks in one PTI plot we checked the footage from the camera trap we placed on the plot and observed multiple deer fawns walking across the plot. Due to the high error rate and uncertainty in our detection capability along with the time consuming setup, we determined that the PTI method was not an effective monitoring strategy for Tejon Ranch Conservancy during summer months.

### *Camera Traps*

Camera traps have been used as an effective tool for population monitoring in a number of settings. The advantages of motion sensing camera traps are numerous and well documented. We employed motion triggered camera traps as our primary tool for monitoring due to their availability, efficient setup, and unambiguous detection capabilities. Using camera traps we were able to accurately record pig presence and activity at each sampling location. The effectiveness and practicality of camera trapping as a monitoring tool is further discussed in the context of its statistical power in 5.4.3 Results.

### *Scat Surveys*
Scat surveys have been used successfully in other studies to estimate the relative abundance of species, including wild pigs (Kunkel et al. 2005). In this method, transects are established and all scat found in them is initially removed. After a certain amount of time, several days for example, transects are canvassed, and any scat found is collected once again. A scat index is created as "number of scat collected/transect/ deposition period" (Kunkel et al. 2005). The validity of using scat deposition rates to estimate relative population abundances have been demonstrated in several studies (Knowlton 1994). Based on our initial observations within the study area and the scarcity of pig scat at sites where other pig sign was prevalent, we chose not to field test the effectiveness of scat surveys as a monitoring tool. However, the literature has shown that scat surveys combined with genetic analysis can produce accurate population estimates and information on population structure and genetic diversity. An initial understanding of the seasonal variability of pig distributions on the Ranch could improve the feasibility of this method.

### *Hunter Survey*
Surveys of resource-users have been used to detect trends in animal populations and are inexpensive and practical to administer (Kunkel et al. 2005). We developed a survey for hunting guides and hunters to assess their local knowledge about wild pig abundances, spatial distribution, and affected areas on the ranch (Discussed in Chapter 2). While we found this information to be useful for detecting trends in hunter knowledge and hunting preferences on Tejon Ranch, we concluded that this survey format was not effective in determining pig population abundances. The effectiveness of resource-user surveys depends upon the number of participants and the completeness of their local knowledge. The responses we received from our survey were not robust or numerous enough for us to establish a population abundance index.

### *Harvest Data Collection*
Waithman et al. (J. D. Waithman et al., 1999) have used hunting data to generate rough population estimates for wild pigs. The collection of harvest data is already required for all hunts that occur on Tejon Ranch. This data includes harvested pig weight and sex, along with time, date, and general location of each kill. Despite this, the Hunting Program at the Ranch was unable to provide us with complete harvest data. The data were not easily accessible and were not entered electronically. Without a complete data set we will not be able to develop a population estimate. We recommend a review of the data collection and sharing practices between the Tejon Ranch Hunting Program and the Tejon Ranch Conservancy to ensure adherence to Best Management Practice as outlined in the RWMP. The use of harvest data has the potential to be extremely valuable as a monitoring tool and is necessary for understanding pig population structure and responses to hunting pressure. Regular data sharing between the Ranch Company and the Conservancy will contribute significantly to monitoring efforts.

## 5.3.2 Monitoring Wild Pig Damage

We monitored wild pig damage in conjunction with pig abundance in an attempt to correlate a specific amount of damage with the number of pigs that caused the damage. As stated in Chapter 4, wild pigs can cause extensive rooting damage as a result of their feeding behavior. This rooting behavior and the disturbance it causes has a number of negative environmental and ecological impacts. Thus, the seasonal variability in extent and location of actual damage is of greater concern for the Conservancy than population abundance. Additionally, determining the correlation between abundance and damage can allow approximation of one from measurement of the other. This could result in substantial cost savings to monitoring programs.

### *Fresh Damage Index*

One way to estimate effects of feral pigs on terrestrial plant and animal communities is with a Fresh Damage Index similar to the one developed by Engeman et al. (2001). This method estimates the percentage of fresh rooting in fixed 10m x 10m plots along transects. This can provide information on the extent and distribution of rooting activity and the resulting damage. We modified Engeman's method and paired damage plots with motion sensing cameras during our pilot study. This allowed us to correlate abundance with damage. Specifics from the methods utilized are discussed further in 5.4.2 Methods.

Throughout the summer, we found that damage estimation was especially successful in riparian habitat where fresh damage was easily seen in the form of pig wallows and rooted streambeds. Measuring damage in terrestrial habitat was more difficult due to the dry conditions on Tejon Ranch during the summer. Our recommendations for this monitoring method (discussed further in Chapter 7) reflect our advice that the Tejon Ranch Conservancy also measure damage in terrestrial plots in wet seasons when terrestrial damage is more easily seen than in the summer. With indexes of pig damage in all seasons, the Fresh Damage Index will be an effective method to measure pig damage in both riparian and terrestrial habitats.

### *Other Damage Indices*

Other methods to quantify wild pig effects on ecosystems are included in the feral pig chapter of the Tejon Ranch RWMP and may be applicable for future consideration. One method involves taking a large-scale snapshot in time of all the pig damage in a given area (Chavarria et al. 2007). Pig damaged habitat is geo-referenced in each place it is observed and these estimates are compiled across the entire landscape to inform total habitat damage. Another method combines damage monitoring with a given plot's distance to water sources (Chavarria et al. 2007). Half of damage transects are placed <50 m from major hydrological sources (i.e., creeks and rivers), while others are placed >500 m from these water sources. Since pig abundances are limited by water resource availability during the summer or dry season, the results of this monitoring could be useful in determining priority areas for control efforts. We performed post-hoc spatial analysis of our damage data from the summer (see Section 5.4.3) to determine correlations between damage index and several environmental variables, however these methods could be more effectively used if they were incorporated into a monitoring regime from the outset.

## 5.4 Pilot Study

Based on our initial evaluation of monitoring techniques, we conducted a pilot study of pig abundance and damage using paired camera traps and damage plots (see Methods section below for details). This technique enabled us to establish an initial index of pig abundance and damage within the watersheds of Tejon Creek, El Paso Creek, and part of Cottonwood Creek. The data were then used to compare index values between vegetation types and to test the correlation between pig abundance and damage. We found no significant correlation between pig abundance and damage in the terrestrial transects and a highly significant correlation between pig abundance and damage in the riparian transects.

The spatial component of the data allowed us to test correlations between the indexes and other environmental variables. The data were also used to evaluate the effectiveness of our method using a post-hoc power analysis and an estimate of cost-effectiveness. We found that increasing the number of cameras and the duration of each camera sample will contribute to a more sensitive and cost effective monitoring strategy. We also found it difficult to reliably distinguish between rooting damage and other forms of ground cover disturbance during the hot dry summer months and recommend that sampling be conducted during the wetter months to improve detection of fresh damage and compare the distribution of abundance and damage between seasons.

### 5.4.1 Study Area

We conducted our study within the Tejon Creek, El Paso Creek, and western end of Cottonwood Creek watersheds on Tejon Ranch (Figure 22). Tejon Ranch is located in the Tehachapi Mountains east of the town of Lebec and constitutes a regionally important landscape linkage between the Coast and Transverse Ranges to the west and the Sierra Nevada to the east. The study area was chosen for its diversity of habitat types, elevation, ease of access, and known presence of pigs. The western side of Cottonwood Creek watershed was added to obtain an even number of replicate transects in each vegetation type. Combined, these watersheds comprise approximately 75,000 of the 240,000 acres of conserved land at Tejon Ranch.

Several disturbance areas and human uses exist within the study area. These include residential areas, agricultural areas, historical buildings, oil and gas infrastructure, power lines, hunting cabins, an aqueduct, and a network of gravel roads. The degree to which these impacted our ability to establish random sampling locations was minimal. However, the road network facilitated sampling over the large area.

Using ArcView 10.1 software and previous delineations of vegetation type, we chose five categories of vegetation cover to stratify the study area. These were: Grassland, Savannah, Woodland, Chaparral, and Conifer. Together, these vegetation types map very closely to the major vegetation types listed in the RWMP with the additional distinction in our study between Woodland and Savannah. These major vegetation types encompass the entirety of the study area and represent a wide range of biotic communities and environmental variables (see RWMP for details) all of which may be potential wild pig habitat.

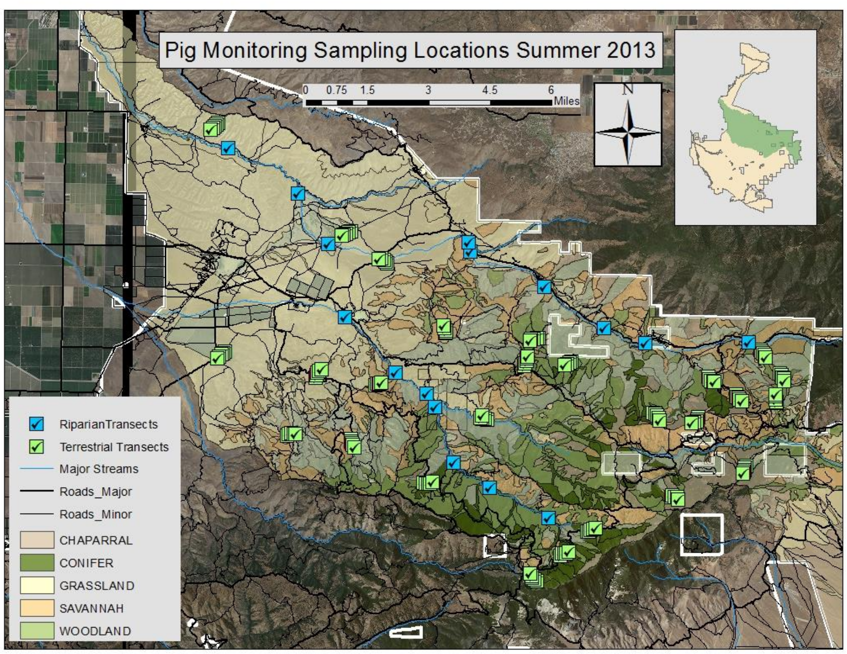


**Figure 22 Map of pilot monitoring study area and camera sampling locations during summer 2013, Tejon Ranch, Kern County, CA**

## 5.4.2 Methods

### *Sampling Site Selection*

We used ArcGIS (version 10.1) software to randomly select sampling locations within each vegetation type and in riparian areas. We then used the near tool to find points that were nearest to a secondary road for our terrestrial transects and moved each point to the closest secondary road feature to represent the starting point for a terrestrial transect. Riparian transect starting locations were randomly selected at points along each creek. Roads running along each creek allowed relatively easy access to each riparian transect.

An excess of potential sampling locations for each vegetation type was generated so that sampling sites could be selected based on feasibility. Some sampling locations generated using Arc were not possible to sample due to some roads being blocked or inaccessible. Having extra sampling locations allowed us to efficiently reassign sampling locations on the fly while in the field. Sites were also selected to represent as many different patches of each vegetation type as possible with five transects.

Based on our initial testing of monitoring methods and our supply of cameras, we estimated that we would be able to sample approximately 25 terrestrial transects during the duration of the pilot study. This would give us five transects in each vegetation type. Our resource and time limitations prohibited us from resampling at the same location.

We used a random sampling design due to reports from the Ranch that wild pigs have been seen throughout the landscape with no barriers to pig movement within the sampling area. A stratified random design also allowed us to correlate pig activity to spatially distributed environmental variables.

### *Terrestrial Transects*

Following the methods outlined by Engeman et al. (2001), we positioned five camera stations with paired damage plots along 0.5 km transects that followed secondary roads. Placing transects along secondary roads allowed us to minimize vehicle traffic on transects as compared to placing them on primary roads. Previous studies have shown that wild pigs are not deterred by roads and often use them and forage near them (Fleming 2001). Additionally, placing camera traps and damage plots along secondary roads allowed efficient setup and data collection.

Five paired camera traps and damage plots were placed along each terrestrial transect. When possible, cameras were positioned with the damage plot in view. When triggered, cameras captured 30 seconds of video. Our preliminary tests showed that video more accurately captures large groups of pigs than still shots, and can provide additional information such as the predominant actions the wild pigs were engaged in during the capture. Camera captures were in full color unless the IR camera was used for illumination. Videos were then reviewed and number of pig detections and other wildlife detections in each video were recorded. Due to the difficulty of distinguishing individual pigs, each video was counted as a separate sample regardless of the time between captures. Group size was recorded as the total number of pigs occurring in each video.

Damage plots consisted of a 10m x 10m plot adjacent to the road with two corners marked with small flags. The area of rooting damage was estimated for each quadrant of the plot and then averaged. Sampling periods were between 3 and 7 days (Figure 23).

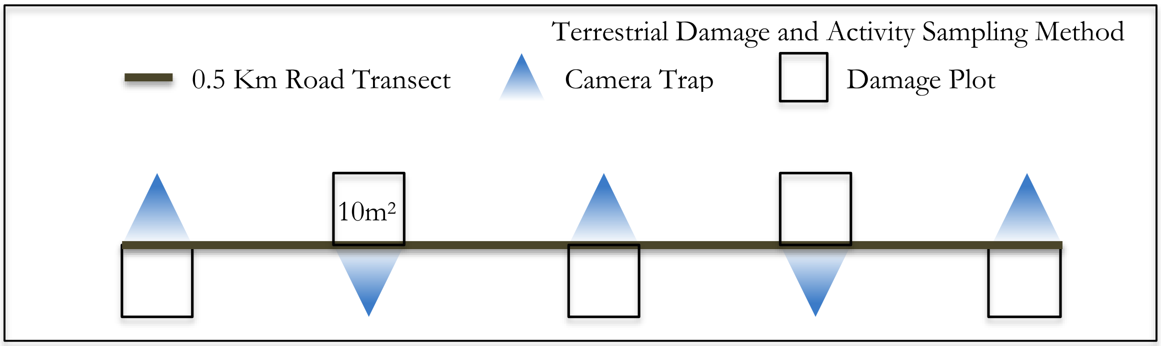


**Figure 23 Diagram of terrestrial damage sampling methods. The width of damage was measured every 5m along a 50m reach. The area of the set of rectangles generated from this approach was used as our terrestrial damage estimate.**

## *Riparian Transects*

Sixteen riparian transects 50m in length were randomly placed along Tejon Creek and El Paso Creek with a minimum distance between transects of 0.5km. Pig activity was assessed with a minimum of two, and up to four, cameras per transect depending on site conditions. We placed as many cameras on the stream as needed to visualize the entire 50m reach of each transect. Damage was assessed by measuring the width of impacted area every five meters along the "river right" side of the stream (Figure 24). We defined impacted area as any area within the streambed or the riparian zone with evidence of wallowing, rooting, grubbing, or heavy traffic. This provided an estimate of total area damaged along the 50m reach.

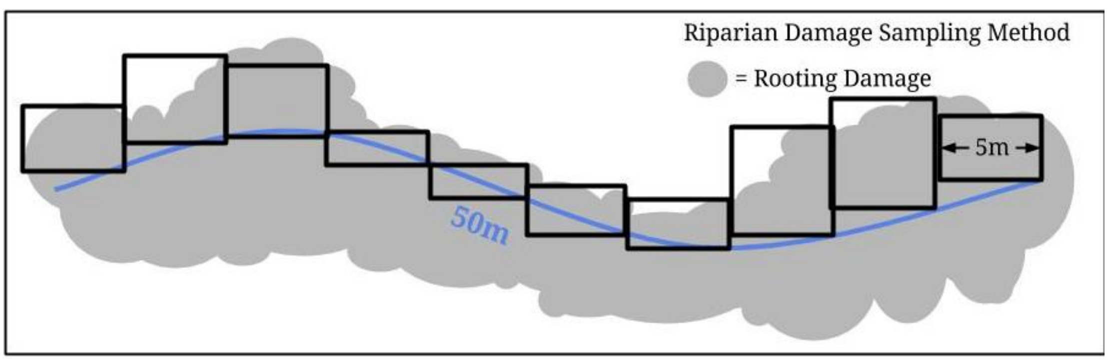


**Figure 24 Diagram of riparian damage sampling methods. The width of damage was measured every 5m along a 50m reach. The area of the set of rectangles generated from this approach was used as our riparian damage estimate.**

## *Index Calculation and Statistical Analysis*

For terrestrial transects our abundance index was calculated as (#pig detections/camera/night). This is slightly different from our riparian index. Because there was variation in the number of cameras placed at each transect we used a different calculation for our index (#pig detections/night).

Statistical analysis of the data was done using the open source R (version 3.0.1) statistical programming package. We used this software to conduct an analysis of variance on our data using the means of each damage and abundance index for each vegetation type. We computed the correlation between damage and abundance overall and for each vegetation type. We used R to run correlation tests between our indexes and several environmental variables (elevation, distance to stream, distance to any water source, and other mammal activity) that we suspect may influence feral pig abundance and damage.

### *Power Analysis*

Power analysis was conducted using R. We calculated the number of samples needed to detect a significant difference in each of our mean index values over a range of effect sizes from 25% to 100%.

### *Cost Effectiveness Estimate*

We estimated the cost per sample for both terrestrial and riparian transects based on the average daily productivity of one worker and multiplied this by the number of samples needed to detect a given change in mean abundance and damage indexes.

## 5.4.3 Results

### *Activity and Damage*

From June to August 2013 we collected 293 total observations of feral pigs and documented rooting damage at 46 terrestrial damage plots and 15 Riparian plots within the study area. A summary of our samples is included in Table 3. A summary of our observations is included in Table 4.

**Table 3 Sampling Summary**

| **Vegetation Type** | **No. Transects** | **No. Plots** | **No. Camera** |
|---|---|---|---|
| Grassland | 5 | 25 | 100 |
| Conifer | 5 | 25 | 100 |
| Chaparral | 5 | 25 | 105 |
| Woodland | 5 | 25 | 95 |
| Savannah | 6 | 30 | 80 |
| Riparian | 14 | NA | NA |

**Table 4 Summary of observations**

| Vegetation Type | Mean Abundance Index Value & SD | No. Detections | Mean Detected Group Size | Max Group Size | Mean Damage Detected ($m^2$) |
|---|---|---|---|---|---|
| Grassland | 0.0013 ± 0.018 | 1 | 1 | 1 | 0±0.00 |
| Conifer | 0.0928±0.527 | 17 | 2.53 | 13 | 3±6.00 |
| Chaparral | 0.2171±1.755 | 38 | 2.79 | 13 | 8.7±10.08 |
| Woodland | 0.0419±0.077 | 10 | 1 | 1 | 22.83±15.37 |
| Savannah | 0.0130±0.035 | 4 | 1.25 | 2 | 20.1±11.78 |
| Riparian | 3.8229±6.46* | 223 | 2.86 | 18 | 75.31±51.43 |

**Summary of case study observations means and standard deviation based on transects as the sampling unit. Index value is calculated as number of pigs observed/camera/night (* Riparian transects are calculated as (number of pigs observed)/night).**

We did not observe a statistically significant difference between activity and vegetation type (Figure 25), however we did observe a difference in rooting damage between vegetation types with significantly more damage occurring in woodland and savannah than in conifer and grassland vegetation types (Figure 26).

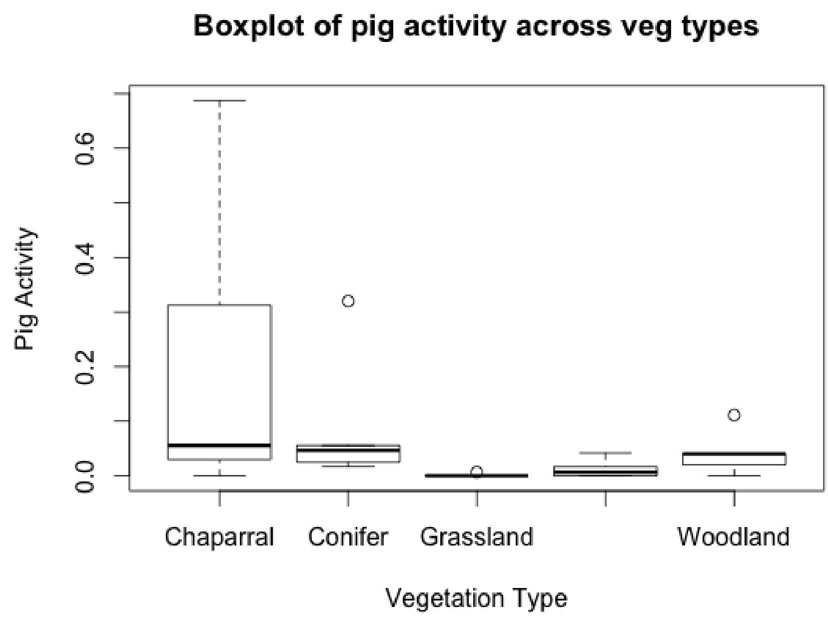


**Figure 25 Comparisons of pig activity across vegetation types. ANOVA showed no significant difference in activity across vegetation types (p = 0.135). Whiskers represent endpoints, boxes enclose the first and third quartiles. Dark lines indicate the median and circles represent outliers in the data.**

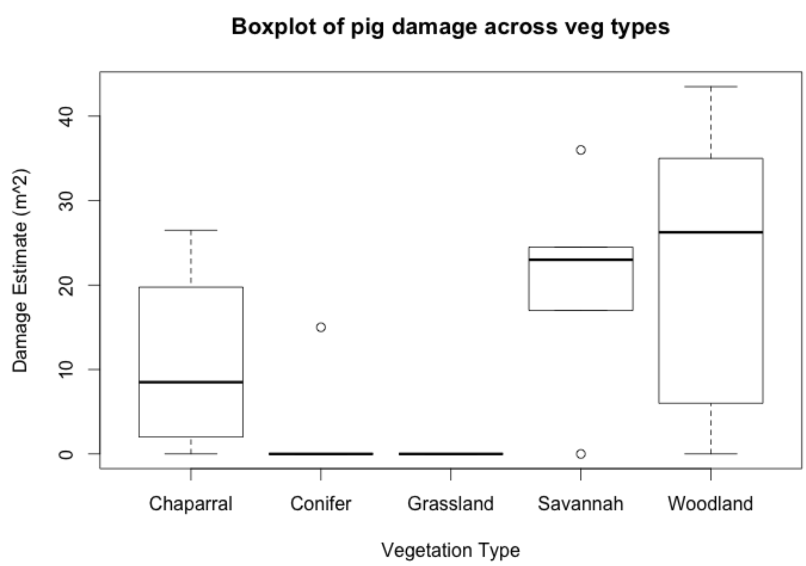


**Figure 26 Comparison of pig damage across vegetation types. ANOVA showed that observed rooting damage varied significantly across vegetation types (p = 0.0127).**

Our correlation test revealed a significant positive correlation between pig activity and elevation showing that elevation explained approximately 22% of the change in pig activity, with pigs being observed more often at higher elevations (Figure 27). We also observed a highly significant correlation between riparian pig activity and rooting damage (Figure 28).

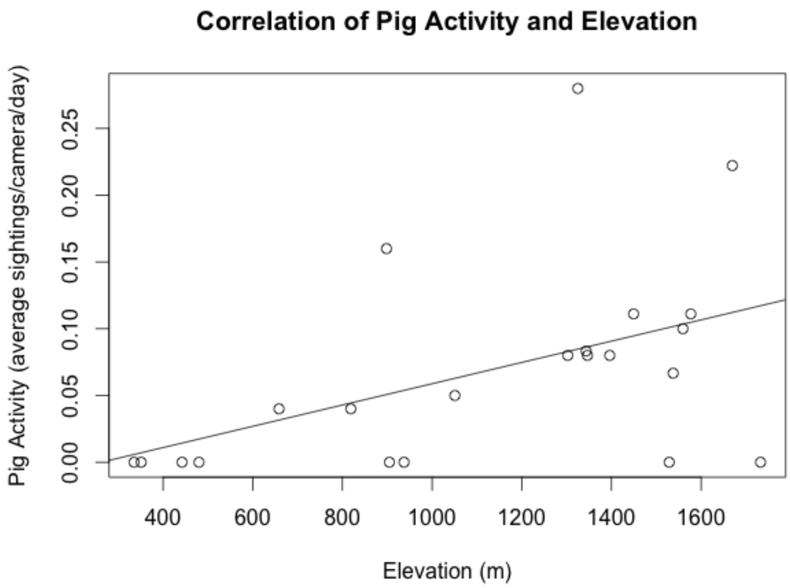


**Figure 27 Regression analysis of pig activity index and elevation shows a significant positive correlation ($R^2$ = 0.2211, p = 0.01).**

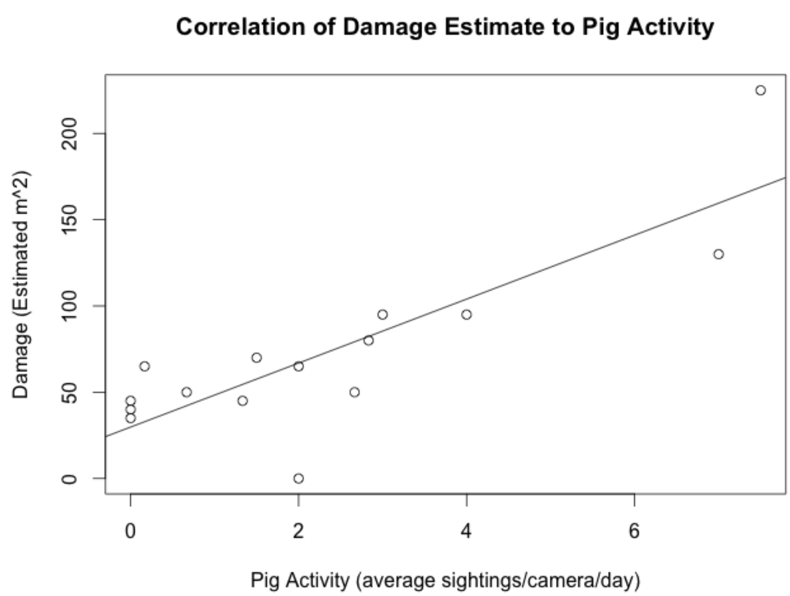


**Figure 28 Regression analysis of riparian pig activity index and damaged area shows a significant correlation ($R^2$ = 0.68, p = $9.162 \times 10^{-5}$).**

## *Power Analysis*

We chose to disaggregate cameras from transects and to test the power of individual camera samples to see if the amount of time a camera stays in the field would have a significant impact on its utility in detecting pigs. A single camera sample is a single instance of placing a camera in the field, letting it record data, and retrieving it. This allowed us to use our data to estimate the number of individual camera samples we would need to take to detect a given change in our pig abundance index. Because the cameras were out for different numbers of days, we initially limited the power analysis to the first three days of each camera sample so that our data was normalized.

Across vegetation types, the mean abundance index was approximately 0.31. To detect a change in the abundance index of 50% (0.15 index value) would take more than 6000 cameras placed in the field. To further test the power and limitations of our sampling design we took a subset of the camera samples that were placed in the field for 7 days and performed the power analysis again. Figure 29 shows that increasing the number of days a camera is in the field from 3 to 7 reduces variability in the data and the number of samples needed to detect a change.

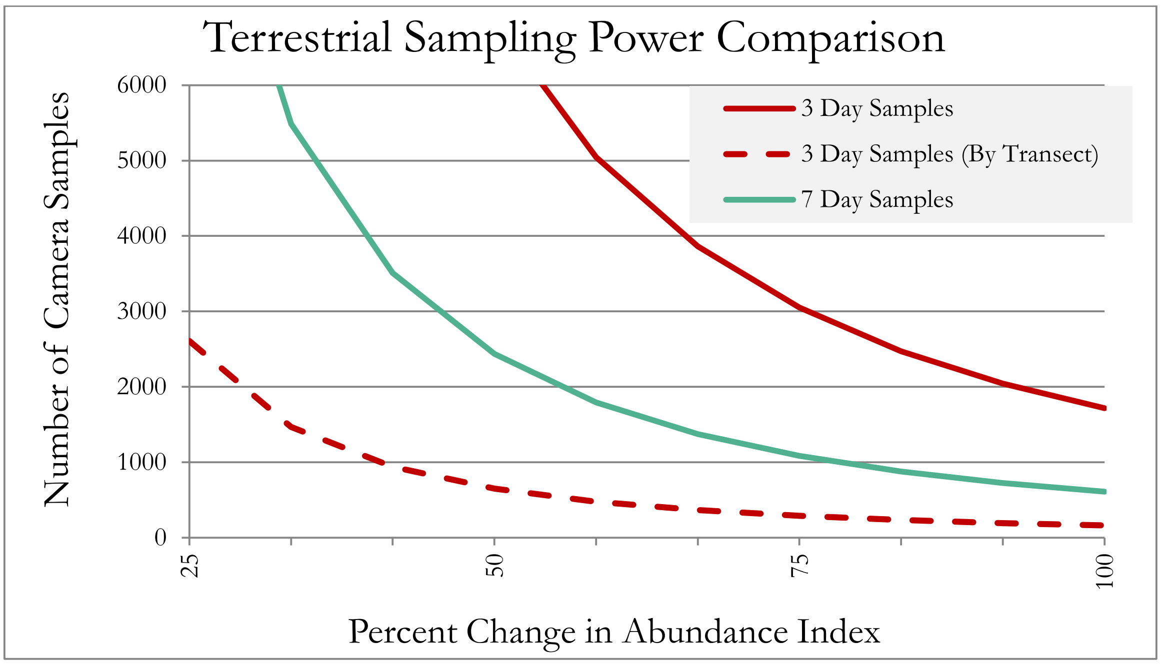


**Figure 29 Power analysis comparisons of terrestrial camera sampling, demonstrating the relationship between number of camera samples and ability to detect a change in mean pig abundance index. Samples marked as "3-Day Samples (by Transect)" were grouped together by transect. Mean index value (0.31 ± 1.57).**

Based on our findings of the most prevalent and detectable damage in the riparian area, we also performed a power analysis on our riparian damage sampling with encouraging results (Figure 30).

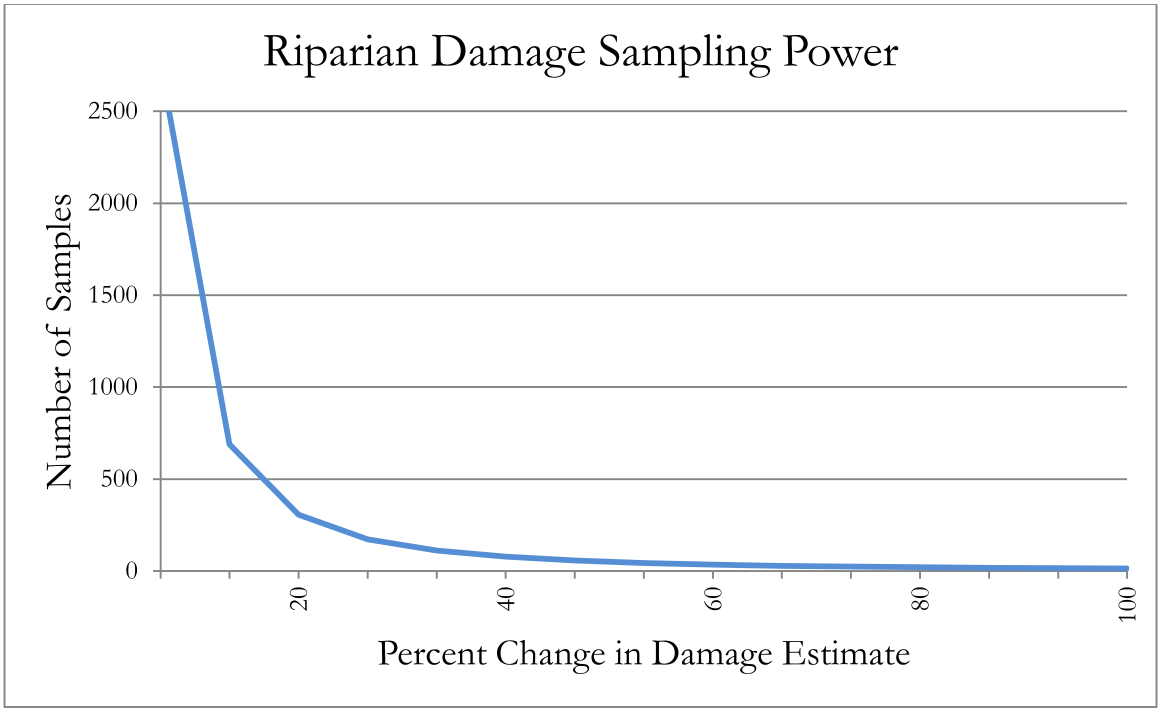


**Figure 30 Power analysis of riparian damage sampling showing relationship between the number of damage samples and the ability to detect change in the amount of damaged area. Mean damaged area (75.31±51.43 m$^2$).**

Power analysis of our riparian damage sampling technique shows we need far fewer samples to detect changes in riparian damage compared with detecting changes in our pig abundance index. Whereas over 1000 camera trap nights were necessary to detect a small change in pig abundance, here we can detect a relatively small change in damage with a relatively small number of samples. For example, to detect a 30% change in damage we would need 170_riparian transects. Based on these data, we would recommend the conservancy pursue damage monitoring in riparian zones as a proxy for pig abundance. This should be done in conjunction with camera traps along the riparian transects to maintain the correlation between damage and abundance.

### *Cost Effectiveness*

With the results of the power analysis and estimates of cost per sample based on our work last summer we calculated the estimated cost of detecting a 30% change in the terrestrial abundance index and riparian damage index (Table 5).

**Table 5 Iterated costs of different sampling methods**

| Sampling Method | # of Samples Needed | Cost |
|---|---|---|
| **3-Day Camera Traps** | 15,5000 | $691,610 |
| **7-Day Camera Traps** | 5,500 | $245,410 |
| **3-Day Camera Transects** | 1,400 | $312,340 |
| **Riparian Damage Transects** | 170 | $6,135 |

**Estimated cost of detecting a 30% change in abundance and damage indices for various sampling methods.**

Based on preliminary conversations with the Conservancy, a 30% change was for the purpose of illustration. This number is not based on a specific damage control target. We can see clearly from this rough estimate that monitoring for riparian damage is much more cost effective. It should be noted, however, that increasing the number of cameras deployed could significantly lower the cost associated with camera trapping methods and the cost of purchasing additional cameras would be offset by the reduction in labor costs. Additionally, if the trend of increasing camera sample length were to continue, placing cameras in the field for extended sampling periods could further reduce the cost of camera trapping techniques.

### *CHOOSING A MONITORING PROGRAM*

A variety of methods have been used to monitor wild pig populations and to determine the efficacy of pig abundance and damage control and recovery efforts (Vongkhamheng 2013, Bengsen 2011, Reidy 2011, Gopalaswamy 2012, Ebert 2012). In a comprehensive review of methods, Engeman (2013) outlines the most desirable qualities of a variety of monitoring methodologies, which include practicality, sensitivity, precision, variance estimation, and robustness. The results and analysis of our pilot study provide important information on these qualities and can be used to inform future monitoring efforts.

As the Conservancy continues to develop an effective monitoring program for wild pigs and their effects on the ranch it will be critical to continue to evaluate and iterate on the specific monitoring strategies and techniques they choose to employ. To this end there are several lessons we have learned from this pilot study that should be applied to future monitoring efforts. We had a limited timeframe in which to collect data and only collected data during the dry summer months. This prohibited us from detecting seasonal variations in pig abundance and damage in each vegetation type, information that would be extremely useful for implementing population control efforts. Similarly, we found it very difficult to accurately measure pig damage in the terrestrial plots due to the lack of green vegetation on the ground. Monitoring for damage during wetter months and returning to those plots during dry months may help identify features of disturbed areas that improve damage detection during future monitoring efforts. We were also limited by the number of cameras available to use and were only able to collect 29 samples at a given time.

The lessons learned from this pilot study have led to a number of recommendations for pig monitoring efforts in the future. We have shown that indices can be an effective way to measure feral pig damage and abundance and should continue to be pursued as a monitoring approach with modifications to the specific sampling techniques. We feel strongly that monitoring of damage and abundance should be conducted in all seasons and in all vegetation types to assess the seasonal variation in distribution and extent of these important indices. Our power analysis has shown that increasing the length of time cameras are left in the field (sample length) can improve the cost-effectiveness of monitoring which can offset the cost imposed by purchase of additional cameras. Leaving cameras out longer would require more cameras to cover the same geographic extent. Our analysis therefore calls for increasing the number of cameras simultaneously deployed. Additionally, it is important to note that camera trapping has the added benefit of allowing the Conservancy to monitor all large species on the Ranch using the same sampling technique. Thus, we recommend that sightings of all species of interests should be documented and camera traps incorporated into a broader multi-species monitoring effort. Lastly, as stated previously, collaboration with the hunting program in wildlife monitoring efforts will enable more accurate monitoring and a better understanding of wild pig responses to hunting pressure. Data sharing between the Conservancy and the hunting operations on the Ranch has the potential to increase the effectiveness of targeted hunting efforts and identify interactions between wild pigs and other game animals on the Ranch. Furthermore, harvest data and monitoring data must go hand in hand to provide a complete picture of the trends of pig activity on the Ranch.

# CHAPTER 6: MANAGEMENT STRATEGIES

A number of options exist to manage wild pig damage. These strategies can be generally grouped into three categories: eradication, population control, and exclusion. Each of these strategies is discussed below, including an analysis of how they can be implemented on Tejon Ranch.

## 6.1 LOCAL ERADICATION

Local eradication is the complete and permanent removal of all wild pig populations from an explicit area with a time-limited campaign (Bomford & O'Brien 1995). While comprehensive eradication of wild pig populations is the only consistent way to provide ecosystems with long-term respite from their impacts (Van Vuren 1992), such action can be risky, expensive, and logistically challenging.

### 6.1.1 CRITERIA FOR SUCCESSFUL ERADICATION

Several criteria are essential for achieving eradication. First, *the rate of removal must exceed rate of increase of all population densities for the duration of the project*. Although such a criterion seems obvious, several factors can arise to complicate matters. Like other animal populations subjected to control, wild pigs can compensate with high breeding and survival rates because of the increased availability of resources when the population size is reduced. Annual rates of increase in culled wild pig populations have been estimated at 86% (Giles 1980). Furthermore, as the number of pigs inside the eradication area dwindles, the remaining pigs become progressively harder and more expensive to find due to their reduced numbers and because they become increasingly wary of efforts to remove them (McIlroy and Gifford 1997). As a result, removal rates tend to decline at low population densities. However, if the eradication effort does not sustain removal rates above the rate of increase at all population densities, it will fail (Bomford & O'Brien, 1995).

A second criterion of a successful eradication effort is the *prevention of immigration*. If such eradication efforts are undertaken on the mainland, as opposed to islands, potentially extensive and costly fencing surrounding the target property is necessary to keep wild pig populations from emigrating out of its borders during the eradication period and immigrating back once the removal pressure abates. Any further release of additional animals into the eradication area also needs to be prevented (Bomford & O'Brien 1995). Recently eradicated areas can be attractive to outside pig populations because of the increase in food and habitat resources, therefore it is important to maintain closed borders around the eradication area.

A third criterion is that *all reproductive animals must be at risk* in order to avoid population growth or expansion during eradication proceedings. If the effort is to succeed, eventually all reproducing wild pigs would need to be removed (Bomford & O'Brien 1995). This means that females should be targeted more heavily than males to reduce reproductive rates. This is especially important in wild pig eradication because of their high fecundity.

Several additional criteria can help determine whether eradication is preferred to on-going control measures. These include: *animals can be detected at low densities, benefit-cost analysis favors eradication over control,* and *a suitable socio-political environment exists.* Additionally, eradication projects tend to be more successful the sooner that eradication efforts are attempted after an introduction of wild pigs (Bomford & O'Brien 1995).

## 6.1.2 METHODS USED FOR ERADICATION

A number of methods used to eradicate pigs are also used to control their populations as well. These methods include aerial gunning, ground hunting (with or without dogs), and trapping. These methods are discussed in the control section below. The Judas pig technique tends to be used solely in eradication programs and as such is discussed here.

### *JUDAS PIG TECHNIQUE*

The "Judas" technique was developed at Hawaii Volcanoes National Park by Taylor and Katahira (1988) as a method for finding the remaining animals during eradication efforts. Originally developed for wild goats, the technique has since been adapted for wild pigs in Australia, New Zealand, and the U.S. (Wilcox et al, 2004a).

With this technique a wild pig is captured, usually with a box trap, immobilized with a sedative, ear-tagged and fitted with a satellite collar equipped with GPS receivers, and released (Rick A. Sweitzer; Blake E. McCann 2007). Because pigs are social animals, the tagged pig will search out other pigs. These GPS enabled collars can precisely pinpoint where a collared animal and its group is, enabling mangers to track the group's movements and locations from their computers. Such knowledge can help relay information about population movement patterns, document habitat and wildlife destruction, and better target removal efforts where most needed, such as in sensitive riparian areas (Hartley, Spear, & Goatcher 2012). Once the Judas pig's location is established, one can stake out the location while the pigs are there and wait for an opportunity to shoot associated pigs. Alternatively, their locations can be noted and then assessed for damage in following days.

### *COMPARISON OF ERADICATION PROJECTS IN CALIFORNIA*

Several wild pig eradication projects have been undertaken in California, their relative project characteristics are displayed in Table 6. Specifics on the fencing component of several of these projects are discussed in the fencing section below.

**Table 6 Six wild pig eradication programs occurring in California (1973-2006)**

| **Program Characteristics** | **Annadel State Park** | **Pinnacles National Monument** | **Santa Catalina Island** | **Santa Rosa Island** | **Santa Cruz Island** |
|---|---|---|---|---|---|
| **Project duration** | 1985-1987 | 2003-2006 | 1990-2005 | 1991-1993 | 2004-2006 |
| **No. pigs removed** | 144 | 200 | >12,000 | 1,175 | 5,036 |
| **Area (km2)** | 20 | 57 | 194 | 215 | 249 |
| **Cost of fencing ($)** | 90,000 | 2,000,000 | 941,672 | 0 | 1,224,001 |
| **Total expense ($)** | 165,000 | 2,626,202 | 3,402,290 | 795,000 | Information not complete |
| **Removal technique employed** | Trapping and dogs | Trapping, ground-hunting, dogs, Judas animals | Trapping, dogs, ground-hunting, sport hunting | Dogs, ground-hunting, aerial-shooting, and trapping, | Trapping, aerial shooting, ground-hunting, and dogs |
| **Monitoring techniques** | Transects | Transects and bait sites | Transects and searching | Transects and aerial survey | Transects and searching |

Adapted from McCann & Garcelon, 2008.

### *Conclusions*

The six criteria discussed above in 6.1.1 Criteria for Successful Eradication" were used to evaluate whether or not eradication was an option for wild pig management on Tejon Ranch. Assuming that the rate of removal would be greater than the rate of increase of pigs, which is currently unknown, and that all reproductive animals would be at risk, eradication on Tejon Ranch would still not meet at least three of the other criteria mentioned. Currently, there is no way to prevent immigration of the pigs from surrounding properties to Tejon, and a fence would need to be built and maintained to achieve this. This would be financially and logistically difficult given the size and extent of the Ranch.

Perhaps most importantly, CDFW's classification of pigs as a game species makes the likelihood of receiving the necessary permissions to eradicate such a large population extremely low. Finally, there is currently a commercial hunting program in place on the Ranch, and hunters have expressed interest in seeing more pigs on the property. All of these factors combine to make an eradication program infeasible at this time.

## 6.2 Lethal Control

In cases when eradication is not feasible, a number of lethal control options are available to manage wild pig populations and to limit the damage they cause. These methods include techniques such as targeted hunting (whether ground or aerial and with or without dogs), trapping, snaring and contraceptive control. These strategies are discussed below.

Lethal control involves reducing pig densities to levels that result in less damage to Ranch habitats. However, an important consideration is just how many pigs need to be removed from an area in order to reduce the density to levels that result in less damage. Numerous studies have attempted to relate pig damage to wild pig density or abundance in specific locations (Hone 1988, Vtorov 1993, Choquenot et al. 1996). The results of this research suggest a curvilinear relationship between pig density and damage, meaning that a moderate reduction in pig density (20-30%) may lead to a small or no reduction in damage, while a reduction of 40-50% may significantly reduce damage in an area (Hone 1995, Choquenot et al. 1996, San Diego Feral Pig Eradication and Control Project Final IS/MND 2013). Taking into account this curvilinear relationship between damage and wild pig abundance and other research (Waithman et al. 1999, Sweitzer et al. 2000), it has been estimated that a 35-45% reduction in wild pig density in locales in northern California would lead to significantly reduced pig damage (San Diego Feral Pig Eradication and Control Project Final IS/MND 2013)

It should be noted that these rates refer to decreases in pig densities rather than pig harvest rates. Other studies have shown that in order to effectively prevent pig densities from increasing, 60-70% of a population must be killed in a given year due to high fecundity and migration of pig populations (Caley, P., 1993; Hone, J. & G.E. Robards, 1980; Timmons, Jared B. et al., n.d.). Therefore, reducing pig densities by 35-45% requires eliminating well more than 70% of a population for any given year.

### 6.2.1 Targeted Hunting

#### *Sows and Piglets*

The effectiveness of hunting to control wild pig populations has been shown to be limited due to the biological and reproductive responses of wild pigs to management pressure. Toigo et al. (2008) found that hunting harvest focused on adult males. These programs had limited hunting pressure on adult females and piglets which reduced the effectiveness of hunting to sustainably manage wild boar populations. They concluded that harvest of piglets and adult females reduced populations more efficiently. Appendix 3: Wild Pig Population Model, illustrates the effectiveness of reducing sow and piglet populations.

Since Tejon Ranch's hunting program is operated for commercial and recreational purposes, the sex selection of Ranch hunters will play a role in deciding whether or not the hunting program can successfully target sows and piglets. As discussed in Chapter Two, the hunter survey was used to gain an understanding of hunter priorities. In our survey 77% of respondents strongly disagree or disagree with the statement "I would hunt sows or piglets to help manage pig populations." Many of those surveyed have harvested sows, suggesting that the attitudes toward harvesting piglets may be a source of opposition.

### *HUNTING FOR BEHAVIOR*

Wild pigs can be especially difficult to manage because they learn and adapt quickly. When hunting pressure is high, pigs often respond by altering feeding strategies or activity in order to avoid detection. They do this either by becoming more nocturnal or by retreating to refuges that hunters cannot or do not frequent (Barrett and Birmingham 1994). While this behavior presents difficult constraints for management, focusing hunting efforts in priority areas where wild pigs are present can effectively "train" wild pigs to avoid these places. This approach is not likely to work in a commercial hunting program given that it requires the hunters to hunt an area even if pigs are absent.

Cromsigt et al. (2013) have introduced the concept of "hunting for fear", where hunting is used to induce a strong behavioral effect in the target animal. If there is increased hunting pressure in these areas, pigs will learn to avoid these areas and move on to other habitats. However, this requires a consistent presence of a threat (such as hunters) in areas where this technique is used. Ways to implement this practice include increased hunting on foot (with or without dogs), year-round hunting, and increased hunting of piglets.

### *CATCH PER UNIT EFFORT AND ABUNDANCE MONITORING*

Hunter success per unit effort can also be used to determine trends in population (as discussed in Chapter 5). This technique is commonly used to determine trends in deer and elk populations and may have some application to wild pig management (Kunkel, 1999; Freddy, 1982; Rooseberry and Wolf, 1991). Catch per unit effort is based on the idea that the ratio of animals harvested or "caught" to the amount of effort expended is proportional to the number of animals in the population (Rooseberry and Wolf, 1991). In this case, catch would be defined as harvest, and effort can be defined by the number of permits issued on the ranch, the number of days spent hunting, or the number of hunters hunting for pigs. Effort is typically measured only by those hunters that were successful and unsuccessful hunters are not included in the calculation. This method also assumes that catch per unit effort is a linear function of population size (Rooseberry and Wolf, 1991). Because hunts are conducted privately on the Ranch, it would be relatively easy to implement a program recording hunter success. While pig behavioral responses may cause pigs to be harder to detect, thereby decreasing hunter efficiency, an analysis of trends would still be valuable to inform management. This can be used to determine if the population is increasing or decreasing after implementing control strategies, and therefore act as a measure of the success or effectiveness of management.

### *CONSTRAINTS OF HUNTING*

There are also costs associated with increased access and traffic on the Ranch that may have diminishing returns over time. There are important constraints to using these strategies, and targeted hunting must be carefully planned if it is to be used as an effective management tool. The socio-political environment and willingness of clients to participate in targeted hunting will also determine the success of a more narrowly tailored management program on the Ranch. If our sample of surveyed hunters on the Ranch is representative of all hunters, then it may be difficult to use hunting as a strategy to reduce piglet populations.

If a hunting program targeted at affecting behavior of wild pigs is implemented, it is important to consider the effects of increased hunter traffic in sensitive and priority areas. If the ecological costs of increased human traffic or disturbance outweigh the benefits of targeted hunting in this area, it may be more effective to implement an exclusion or depredation strategy, discussed later in this chapter. Hunting is calculated as a baseline in our cost benefit analysis (Chapter 7, Appendix 4), the cost benefit analysis tool created in the project can be adjusted to include a cost of implementing a more targeted hunting program.

### *CONCLUSIONS*

Tejon Ranch's existing hunting program lends itself to being incorporated into a management strategy. Hunting can be used in a variety of ways to control populations and keep them out of existing areas that are sensitive to damage. The hunting program also provides a unique opportunity for collaborative management between the Conservancy and TRC, through data sharing and monitoring.

Photographs of four different wild pig trap designs; illustrates the diversity of traps for capturing wild pigs

**Figure 31 Examples of wild pig traps (Sweitzer and McCann, 2007)**

## 6.2.2 TRAPPING

Trapping continues to be one of the most commonly used techniques for wild pig removal in California and across the country (Barrett et al. 1988,(Rick A. Sweitzer; Blake E. McCann, 2007). Trapping in California requires a depredation permit from the CDFW. Traps work well in various types of habitat, are target specific, and, once set up, can be incorporated into routine land management. However, traps can be labor intensive and expensive depending on the type and number of traps needed. Finding an effective trapping strategy can be time intensive and depends largely on surrounding environmental conditions. Certain general guidelines apply to trapping for wild pigs in terms of timing, location, and trap design. These considerations are discussed below.

### *TIMING AND LOCATION*

Trapping tends to be more effective when limited to certain times of the year when natural food resources are limited, such as during the dry summer period in California (Choquenot & Lukins, 1996),Rick A. Sweitzer; Blake E. McCann, 2007). Traps should be located near areas of recent pig sign, along travel corridors such as game paths, and in other areas where wild pig activity is the greatest, usually near a water source and/or thick cover for shade. During hot and arid California summers, it is best to set the traps in the evening and check them early in the morning to prevent stress on the animals from lack of water and shade (Rick A. Sweitzer; Blake E. McCann, 2007).

### *Trap Design*

Various trap designs exist for capturing wild pigs including box traps, corral traps, and panelized corral traps (Figure 31). They employ a variety of triggering devices, from mechanical pressure plates to spring-loaded door mechanisms that the animal trips with their weight. The merits and challenges of each of these methods, as well as the necessity of pre-baiting a trap site, are discussed below.

### *Bait Sites*

Before trapping pigs is possible, it is necessary to know whether or not the local pigs readily accept bait or not, and this is done by pre-baiting the proposed trap site(s) with around 10-20 kg of bait. Lines of bait should be run from nearby game paths or wild pig sign into the larger bait pile inside the trap to attract pigs to the trap. For the one to two week long pre-baiting program, these sites should be checked daily and the bait restocked as needed (Rick A. Sweitzer; Blake E. McCann, 2007).

A variety of baits exist for use. Others who have trapped pigs in California have found that corn or corn-based commercial pig pellets work well. Other types of bait include spoiled produce, dry dog food, ripe fruit, and corn or bread fermented in water for a few days. Land managers in Texas have found that coating the bait in berry or strawberry flavored liquids led to bait sites that were visited twice as often as bait sites that did not use the berry flavoring (Campbell & Long, 2008). Earth-colored commercial pig pellets can be used to minimize the consumption of the bait by non-target species such as birds, but the pellets do tend to disintegrate in moist environments. Other best management practices with pre-baiting for wild pigs include varying the type of bait used among locations and at different times of year. The goal is to find out what type of bait the pigs are attracted to and then scale up its use.

It should be noted that there are various methods for setting up these sites, but Sweitzer and McCann (2007), who have done extensive baiting and trapping throughout California, recommend methods similar to those discussed above. Sweitzer and McCann (2007) set up their trap first and then pre-bait inside it with the door locked open during the initial week. This strategy was also implemented successfully at Sedgwick UC Natural Reserve (Massey, Personal Communication 11/12/13). This strategy works particularly well, because it habituates the pigs to the bait and the trap at the same time. However, if the trap requires a large amount of effort to set up and is not going to be moved around much (often the case with corral traps), it may be worthwhile to pre-bait the site prior to trap construction, to ensure that pigs will readily take the bait.

Additionally, installation of a game camera near the bait site allows managers to confirm the presence of pigs, determine how many there are in a particular sounder (if previous tagging or pigs' color patterns allow it), and then build the appropriate size corral trap for the number of pigs in the sounder (Higginbotham 2012). Having the ability to tailor trap size to sounder size is particularly useful because it does not allow any pigs to escape that have learned to be wary of traps (Holtfreter 2010).

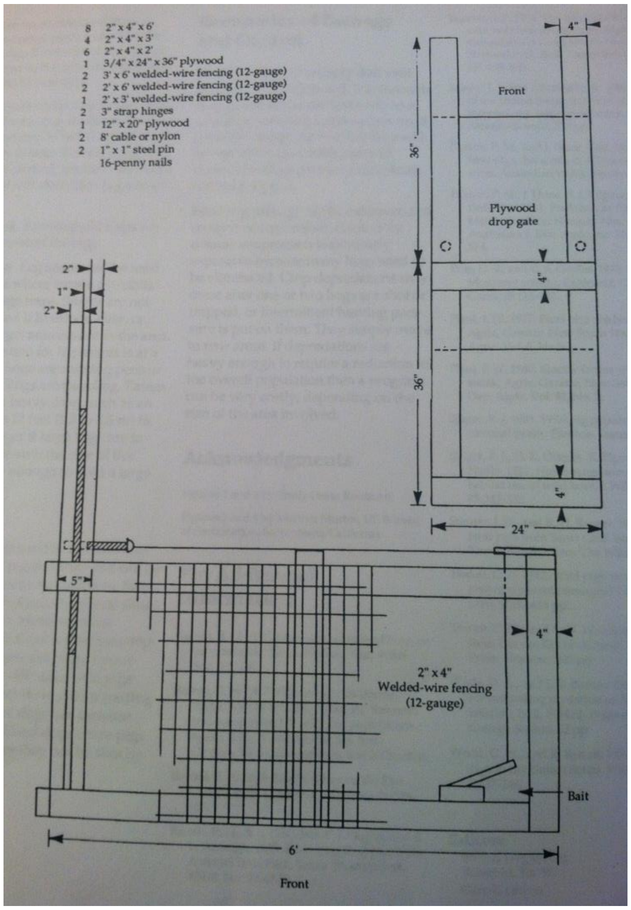


**Figure 32 Portable box trap (Barrett and Birmingham, 1994)**

### *BOX TRAPS*

Because box traps are smaller than corral or panel traps, they are easier to move and transport. However, because they are smaller, they catch fewer pigs in any one trapping episode. Box traps tend to be made out of wood slats or fencing around a pipe or wood frame. Studies from Texas have found that adult males exhibit an aversion to box traps, while adult females enter corral traps twice as often as they enter box traps (Higginbotham 2012).

Recommendations from Barrett and Birmingham (Reginald H. Barrett & Birmingham, 1994) on box trap specifics for USDA Wildlife Services in California are as follows. Build the trap out of 2x4-inch (5.1 x 10.2-cm) welded 12-gauge wire over a 2x4-inch (5.1 x 10.2-cm) wooden frame using a ¾-inch (1.9 cm) plywood drop gate (Figure 32). Place loose barbed wire fencing around the outside of the trap to prevent livestock from entering and to protect both the traps and bait material. When traps are not in use make sure trap doors are locked shut to prevent the possibility of trapping livestock. They also note that such types of traps are especially effective where wild pigs occur intermittently or if only a few pigs were attracted to the bait site. The estimated cost of the materials of a single trap like this is approximately $160.

### *CORRAL TRAPS*

The strength of corral traps lies in their size and ability to catch a larger number of pigs in one trapping episode and corral traps tend to be most effective at capturing female pigs (Choquenot et al., 1993). Still, these types of traps are limited because they are largely permanent, and they require time and labor in the field to assemble them. They can be square, rectangular, circular, or tear drop shaped traps made out of metal t-posts with steel mesh panels wired together around the posts. Circular and tear drop shaped traps seem to work better than square or rectangular because the lack of corners makes it harder to the pigs to climb on top of one another and escape over the top of the trap ((Rick A. Sweitzer; Blake E. McCann, 2007). Places where pigs have gathered in the past and seem to frequent often are typically good places to build a corral trap (Reginald H. Barrett & Birmingham, 1994).

Recommendations from Barrett and Birmingham (Reginald H. Barrett & Birmingham, 1994) on corral trap specifics for USDA Wildlife Services in California are as follows. Build the trap out of steel fence posts and 2x4-in (5.1 x 10-2 cm) welded 12-gauge wire fencing. A gate frame can be made from 2 x 4-inch (5.1 x 10-2 cm) boards. Make doors from ¾ inch (1.9-cm) plywood and mount them so that they open inward and close automatically with springs (Figure 33). Heavier material may be used for the gate and frame in areas where exceptionally large hogs are to be trapped. Also, more steel fence posts may be needed to reinforce the wire fencing. The wire fencing should be put on the ground as well as at the top of the trap to prevent hogs from going under the sides or over the top. Fasten the sides to the top and bottom ((Reginald H. Barrett & Birmingham, 1994). The estimated cost of the materials of a single trap like this is approximately $400.

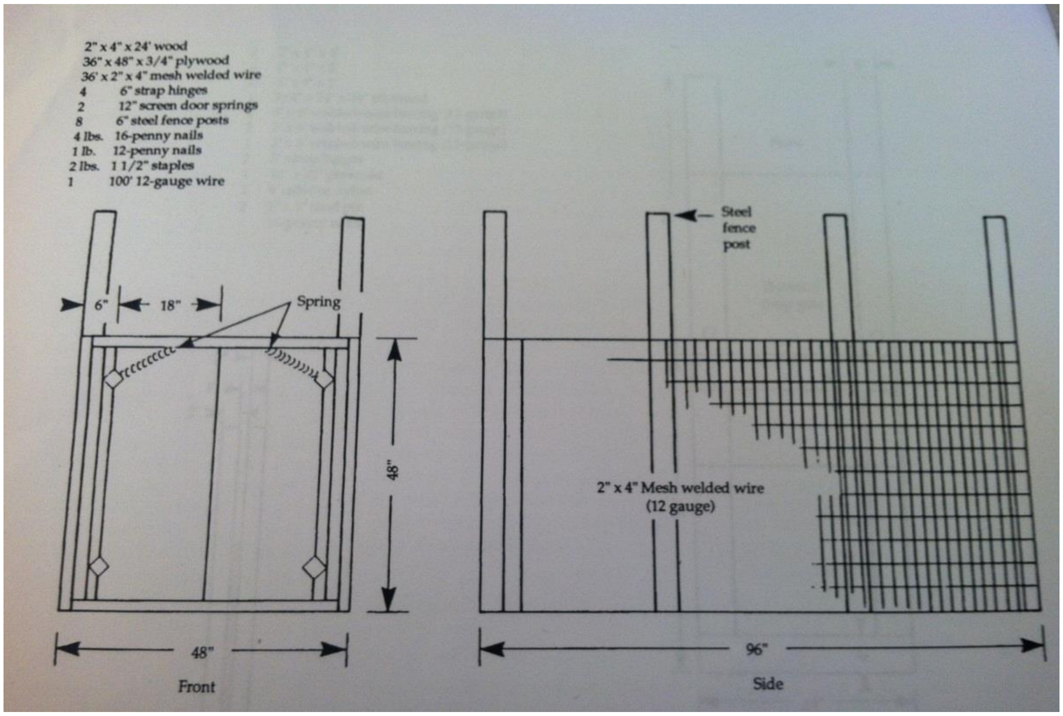


**Figure 33 Stationary corral traps (Barrett and Birmingham, 1994)**

### *Panelized Corral Traps*

These traps are similar in shape and design to the corral traps mentioned above (**Error! eference source not found.**). In order to reduce trap related injuries to pigs that can include lacerations, abrasions, and fractured nasal bones due to the ferocity with which they try to escape, however, this design includes a gated entrance with a runway leading up to the expanded corral section in the rear with a squeeze gate and a lining of the trap's sides with nylon net which prevented pigs from directly contacting the trap panels.

**Figure 34 Panelized corral trap (Sweitzer and McCann, 2007)**

In addition to minimizing injuries, facilitating capture, and safely processing multiple animals, other advantages of the modified panel trap are (1) up to 4 disassembled traps can be transported in the back of a full-sized pickup, and (2) disassembled traps can be moved into remote areas by 2 technicians. Although the trap can be rapidly disassembled, 4-6 hours of labor with 2 technicians is required for assembly.

### *OTHER CONSIDERATIONS*

### Partnering with USDA APHIS Wildlife Services

The number of traps used would be based on the population of wild pigs in a control area. As discussed in Chapter 7, the Conservancy could partner with USDA APHIS Wildlife Services to trap pigs in certain areas on the property. They would employ a number of the techniques discussed above such as putting out traps and bait sites, and their experience with trapping and depredating pigs would be useful. There would be a cost for their time, supplies, and equipment (personal communication, 2013).

### Disposal

A single shot to the cranium with a handgun or rifle kills a pig. Once one pig has been killed, the others in the trap panic and make their subsequent dispatching more difficult to execute as humanely as possible. Sweitzer and McCann recommend "resting the barrel of the firearm on or through the mesh of the side of the trap and picking a location to engage the pigs, rather than attempting to follow each pig around the trap" (Rick A. Sweitzer; Blake E. McCann 2007). It is important to make sure all pigs are deceased before entering the trap, and because pigs can carry a variety of diseases, rubber gloves should be worn for protection.

While California state law requires that pig carcasses from trapping depredation be used if possible, in some cases it is not possible to do so due to high temperatures and remote locations. In these cases, the carcasses can be left for scavenging animals to prey upon, but it should be noted that other wild pigs will eat these carcasses too, especially in periods of otherwise low food resources. Thus, leaving the carcasses could contribute to higher pig populations if subsequent feeding by remaining pigs does occur. Pig carcasses should not be left in streams or creeks or in areas where their remains may be washed into surrounding water bodies due to the negative impacts on water quality and riparian species. Because Tejon Ranch occurs in the condor fly zone, it is important that all dispatch of trapped wild pigs is completed using non-lead ammunition.

### *CONCLUSIONS*

Trapping has been shown to be a successful control method of wild pigs on both the Channel Islands and in other places throughout California and the world (Barrett et al. 1988, Schuyler et al. 2002, Sweitzer et al. 1997a, McCann and Garcelon 2008, Choquenot et al. 1993 and 1996). During eradication efforts, trapping has often been the single most effective method of culling pig populations in early stages before pigs have an opportunity to adapt to the strategy (Garcelon, Ryan, & Schuyler, 2005; McCann & Garcelon, 2008). While the method is efficient, we are hesitant to draw conclusions from these eradication programs about the overall trapping effort needed to reduce pig densities on Tejon. This is due to the fact that the eradication efforts were able to exclude migration of pig species from neighboring lands, while Tejon is likely to see high migration rates.

Trapping success depends on a variety of factors, including topography, time of year, type of trap used, number and density of traps deployed, trap location, number of nights each trap is used, type of bait used, and duration of pre-feeding before the traps are set (Hone et al. 1980, Choquenot et al. 1996, West et al. 2009). When trapping is successful, however, reductions in pig abundances have been as high as 80% (Saunders 1988, Massei et al 2011). Trapping alone in Pinnacles National Monument removed 70% of the wild pig population in the first three months of their eradication program (McCann and Garcelon 2008; Massei et al 2011).

The effectiveness of trapping would be expected to decline during fall and winter when acorns or other natural food sources are abundant and pig abundances in the trapping area dwindle (Barrett 1994, Coblentz and Baber 1987, Schuyler et al. 2002). Other methods such as hunting may be more productive than trapping during fall and winter months, but hunting in the same areas as trapping could lead to reduced trapping success as the hunting pressure could cause the pigs to move to another area.

There is also some difference in effectiveness among the various trap designs available. Williams et al. (2011) studied the efficiency differences between a portable box trap and a semi-permanent corral trap and concluded that corral traps effectively trapped more pigs per trap night at a lower cost per pig than box traps. They pre baited with corn 24 traps, 12 of each style, over a two month period and found that the cost per pig for box traps was $671.31, while the cost per pig for corral traps was $121.28. They note that some landowners or managers may not have different non-trap-related costs (labor, travel, and bait expenses) they did, which could lower costs to $142.12/pig for box traps and to $28.91/pig for corral traps. Still, both stationary corral type traps and mobile box traps have been used successfully in California, and the simplest design for either trap is usually preferable (Sweitzer and McCann 2007).

Intensive hunting and shooting can be used to remove large numbers of wild pigs from a population (Coblentz and Baber 1987, Schuyler et at. 2002). However, opportunistic or incidental shooting is far less likely to have an impact on reducing wild pig numbers. Hunting and shooting require active searching for pigs in the environment, is more labor intensive than trapping, and can be far less efficient than trapping. It is also increasingly less efficient in denser habitat types (Coblentz and Baber 1987, Sweitzer and McCann 2007).

As with any of the recommend wild pig management techniques, it is important to remember that wild pigs are intelligent mammals with a well-organized social structure. Thus, it is important that any control program reduce animal pain and suffering as much as possible. Similarly, trapping requires a depredation permit from CDFW, so its ability to be implemented as a control technique is dependent on collaboration with the land owner (the Company) and CDFW.

### 6.2.3 Aerial Gunning

Aerial gunning is another often used lethal control option where wild pig populations are targeted from small helicopters, this method is typically used when eradication is the goal. Aerial gunning allows for the hunting of pigs over wide swaths of land and over terrain that would be difficult to traverse on foot or in a vehicle. Australian studies have shown that the technique reduces populations by 65-80% (Hone 1990, Saunders 1993) and that the efficiency of the technique increases with increased swine density (Choquenot et al. 1999). Other assessments of aerial gunning efficiency have shown that the tool is efficient and that its use did not result in the widespread dispersal of targeted pig populations (Campbell et al. 2010). Aerial gunning is most effective in large, open lands with little cover (Choquenot, D., Hone, Jim, & Saunders, Glen, 1999). This technique was not evaluated in the cost benefit analysis because it was determined not to be feasible given the cost of the technique, the high incidence of wooded cover on Tejon Ranch, and the low probability of its acceptability as a control method overseen by the CDFW. As with targeted hunting, these costs could be included in the cost benefit framework provided in Appendix 4.

### 6.2.4 SNARING

Due to the high risk that snares pose to other wildlife besides pigs and a statewide ban on some snaring techniques, we do not consider them to be a viable option for use by the Conservancy.

### 6.2.5 CONTRACEPTIVE VACCINES

Currently, researchers at Auburn University are working on developing an inexpensive oral birth control method that is efficient in blocking fertility in wild pigs but not in other animals. Such a contraceptive vaccine could over time significantly reduce wild pig populations in a more effective and less expensive way than the other types of control methods discussed above. The University has already secured two U.S. patents for the intellectual properties associated with the technology and two international patents are pending. The University has also formed a public/private partnership with the Auburn Research and Technology Foundation/PhageCon, LLC for the commercialization of the technology (PhageCon LLC). While this may be a viable control method in the future, it will take time to bear out how effective and appropriate it is for control on Tejon.

### 6.2.6 LETHAL TOXICANTS

Toxicants are currently being developed in other countries, however they are not currently legal in the US. Because of this, we did not consider this to be a viable option for use by the Conservancy.

### 6.2.6 LIMITATIONS AND CAVEATS OF LETHAL CONTROL METHODS

#### *WILD PIG RESPONSE*

Lethal control methods are often used to reduce wild pig densities, assuming that they reduce the population growth rate. The actual effect of lethal removal on density rates, however, has been rarely tested. To address this gap in knowledge, Hanson et al. (Hanson et al., 2009a) explored the effect of experimental manipulation on survival and recruitment of wild pigs by comparing estimates of apparent survival rates (i.e. survival and emigration), recruitment rates (i.e. reproduction and immigration) and population growth between populations of wild pigs inhabiting areas with high and moderate intensities of lethal control (including hunting and trapping) on Fort Benning, Georgia.

Based on their results, which showed nearly equal population growth rates between the heavily harvested and moderately harvested populations, they concluded that as annual survival was reduced in both sites, recruitment rates increased in the population with high harvest intensity. In fact, per capita recruitment in the more heavily harvested population was more than twice what they observed in the moderately harvested population, suggesting robust compensation (Hanson et al., 2009a), which suggests that the extra effort spent to heavily harvest pigs in order to reduce their abundances is counterproductive.

Their recruitment estimates combined reproduction with immigration, which made identifying whether compensation came from increased reproduction or increased immigration into the heavily harvested area impossible. They did find that litter sizes between pigs in the two areas did not differ, but that the number of litters produced in a year by adult females differed by 22%, which suggests a reproductive response. Still, they note that such a response was not enough to account for the differences in mortality that they observed, which means that immigration likely played an important role. Given the extent of wild pig populations on lands surrounding Tejon, this study has great significance for control efforts on the Ranch.

### *Environmental Conditions*

Suboptimal environmental conditions, such as droughts, have the potential to drastically lower wild pig survival and recruitment rates due to the lack of food sources (Giles 1980). Low levels of protein in their diet will cause lactating sows to reduce or stop their milk production altogether, which can lead to substantial piglet losses (Reginald H. Barrett, 1978). Given that California is currently in a prolonged drought, it will be difficult to isolate the effect of management actions on pig populations from the effects of drought conditions.

### *Conclusions*

Survival can be reduced to limit wild pig density and indirectly reduce their ecological and economic impacts however, control efforts must be intensive and on-going to continue reducing the impacts caused by wild pigs. Utilizing a single control method, such as recreational hunting, is unlikely to be effective in controlling pig damage across the Ranch. A patch work of control methods are likely needed to most effectively minimize damage. Decisions about the intensity of control operations should also be informed by the area's environmental conditions. Recommendations for what suite of controls can be used are presented in Chapter Seven.

# 6.3 Non-Lethal Control

## 6.3.1 Exclusion Fencing

Exclusion fencing is one of the most common control techniques for pigs. This approach is highly targeted and can be extremely effective at keeping pigs out of areas of high importance. While often limited in its application due to the high cost of installation and maintenance, fencing generally has the highest success rate among management techniques in terms of limiting damage from pigs.

### *Styles*

Pig fencing can vary dramatically both in terms of cost and effectiveness. There is no single style of fencing that is the best fit for any given locale, rather land managers must figure out their best options based on local conditions and the extent of the pig population they are attempting to exclude. All of the fencing styles described below are assumed to have a 20-year life span.

1) **Non-Electrified**

   A standard fencing style is at least 91 cm high with a strand of barbed wire affixed to the ground, 65-100cm of wire hog mesh (holes 15cm in diameter or less) above that, and 2-3 more strands of barbed wire spaced out on top to prevent pigs from jumping over. Other cases recommend burying a portion of the fence to prevent pigs from tunneling beneath, but it has not been shown that this results in significantly higher rate of success for pig exclusion. Alternatively, securing the bottom strand of barbed wire to the ground has proven effective for long-term exclusion (McCann & Garcelon, 2008). The literature suggests that a stouter fence at initial installation results in significantly lower cost per pig excluded over the lifetime of the fence (Hone & Atkinson, 1983). Non-electric fencing is most applicable for long fences through heavily vegetated areas.

**2) Electrified**

Electrification has been shown to increase the effectiveness of pig fencing, with success rates above 94% exclusion of the wild pig populations (Hone & Atkinson, 1983). However, electrification can seriously increase the maintenance requirements of a fence. Application of herbicides is often necessary to keep vegetation from shorting out the fence, and constant control of plant life may make electrification ineffective for long fences (Tep & Gaines, 2003). On the other hand, electric fences have proven to be the most cost effective fencing style in areas where maintenance or access is not an issue (Hone & Atkinson, 1983).

### *Large Scale Fencing Efforts*

Large scale fencing efforts have significant costs but have proven effective when combined with eradication efforts, discussed above. These fences are non-electrified and generally meet the design suggestions listed above (Table 7). While we recognize that Tejon Ranch will not be conducting eradication efforts, similar fencing techniques can still be used for management purposes.

#### Santa Catalina

Eradication efforts on Santa Catalina Island utilized 29 km of fencing to isolate the wild pig populations. The fencing style utilized consisted of 1m high hog mesh fence varying in mesh size from 5 x 20 cm at the ground to 15 x 20 cm at the top. This fencing style utilized a strand of barbed wire at the bottom to discourage digging as well as three strands of barbed wire above the hog mesh (Garcelon et al., 2005). Manually operated gates were installed for road crossings and volunteers patrolled the fence line once a month and after heavy rains to look for fence damage. This technique proved effective enough to isolate the pig populations for eradication purposes. Total costs for 24 of the total 29 km of fencing were reported at \$825,000 or \$34,375 per km (Schuyler, Garcelon, & Escover, 2002).

**Figure 35 Perimeter fencing at Pinnacles National Monument**

#### Pinnacles National Park

Another major, fencing-dependent eradication effort was completed in Pinnacles National Park in 2003 (Figure 35). This effort required a roughly 39 km fence exclosure with a design very similar to that employed on Catalina. The Pinnacles exclosure used a 65-70 cm high wire mesh with barbed strands running along the top and bottom of the mesh. Two additional barbed strands were put in place above the top of the mesh at 10 and 40 cm (for a total of four barbed strands). The total height of the fence was roughly 110 cm and it was affixed to metal pickets spaced 2.4m apart. The fencing was affixed to the ground using “spade-type structures” in between each metal picket (McCann & Garcelon, 2008). The total cost of the fencing, monitoring, and maintenance was just under \$2 M (Rick A. Sweitzer;

Blake E. McCann, 2007). This exclusion fence was patrolled monthly, and enabled a full eradication effort. An extension of the current fence design was begun in 2009 at a cost of $7.00 per foot for materials and installation (Bouknight, 2013).

### *KEY TAKEAWAYS FROM LARGE SCALE FENCING PROJECTS FOR ERADICATION*

Large-scale fencing projects come at significant cost and commitment to maintenance. Pricing varies significantly depending on terrain features. However, the standard non-electric fencing design (described above) has proven effective at reducing pig damage and facilitating eradication efforts.

**Table 7 Large scale fencing projects and costs of fencing**

| Project | Total Fence Length (km) | Cost per km | Cost per foot | Notes on Fence/Style |
|---|---|---|---|---|
| Santa Catalina | 24 | $34, 375 | $11.11 | Includes supplies and labor for 24 km of total 29 km fence |
| Pinnacles NM | 39 | $51,282 | $14.51 | Includes maintenance costs |
| Pinnacles NM: Kingman Ranch and McCabe Canyon Extension | 7.2 | $22,944 | $7.00 | Includes installation labor and materials |
| Santa Cruz Island (Channel Islands NP) | 44 | $ 28,169 | $8.48 | Includes installation labor and materials |

### *CONCERNS WITH PIG FENCING*

While pig fencing can prove highly effective, there are considerations that should be addressed before installation. Pig fencing is not a control mechanism, rather an exclusion mechanism. In terms of overall damage to an ecosystem, it is best used in conjunction with other control mechanisms such as trapping and hunting (Tep & Gaines, 2003). Pig fencing is a long-term investment that requires substantial maintenance. Even the best constructed fence can be vulnerable to pigs, particularly following heavy rains when the ground is wet and easily dug (Schuyler et al., 2002). Once pigs have breached a fence, they can quickly cause severe damage to the exclusion area. Monitoring of fencing during seasons when wild pig damage is frequent requires at least monthly maintenance and maybe more frequent following large rains or in seasons when pigs are frequenting specific habitats. In seasons where pigs have moved out of the fencing habitat, monitoring may be halted all together.

Finally, while the literature does not provide evidence, it is assumed that pig fencing can have the deleterious effects on the movement of other animal species. While most other wildlife is able to migrate through or over fences, smaller animals may find passage prohibited by the fencing. Quantitative measures of these effects are unknown at this time.

*CONCLUSIONS*

Fencing is widely regarded as an effective means of excluding populations from very limited or very valuable areas. Fences generally require at least monthly monitoring, and maintenance costs can run as high as 20% of the installation cost. Estimates for fencing on Tejon range from $7.00 per foot (from a 4.5 mile fence constructed at Pinnacles NP over highly varied terrain) to $3.25 per foot (from a contracting estimate given to the Conservancy) for flat topography. Given these costs and the high demand for maintenance, creating an exclosure around the entirety of the Tejon property seems highly unfeasible. However, our cost benefit analysis suggests that targeted applications of fencing in high value areas would provide a high return on investment (Appendix 4: Cost Benefit Analysis of Feral Pig Management on Tejon Ranch). The lower cost of installation and maintenance over flat ground in accessible locales suggests that fencing might be particularly cost effective in these locations, while installation in more rugged locales, or those with more variable terrain, is likely cost ineffective. See Chapter Seven for further discussion of cost benefit analysis.

## 6.4 CHAPTER CONCLUSIONS

There are a variety of management strategies available to the Ranch to control damage and abundance of wild pigs. We believe a suite of these strategies can be used to effectively reduce the amount of damage occurring on the ranch from wild pigs, but no single strategy will effectively reduce the population. The next chapter will discuss the group's final recommendations for wild pig management based on our analysis of all the management strategies available to the Ranch.

# 7. Management Recommendations

The deleterious effects of wild pigs on Tejon Ranch are both economic and ecological in nature. Given that the Tejon Ranch Conservancy's mission is based on conserving the habitats protected under easement on the ranch, our recommendations focus on reducing or eliminating pig damage to sensitive habitats throughout the Ranch. Successful efforts to manage pig damage at acceptable levels on a landscape require two primary components. The first is the implementation of damage controls. Damage control is achieved by reducing pig populations from relatively targeted areas, selectively reducing pig populations in high priority areas, and broadly reducing pig populations over larger spatial scales. The second component is a monitoring program that can track the relative success of control efforts and refine the implementation of damage control efforts. The damage control efforts and the monitoring each inform each other, and both are critical for successful management.

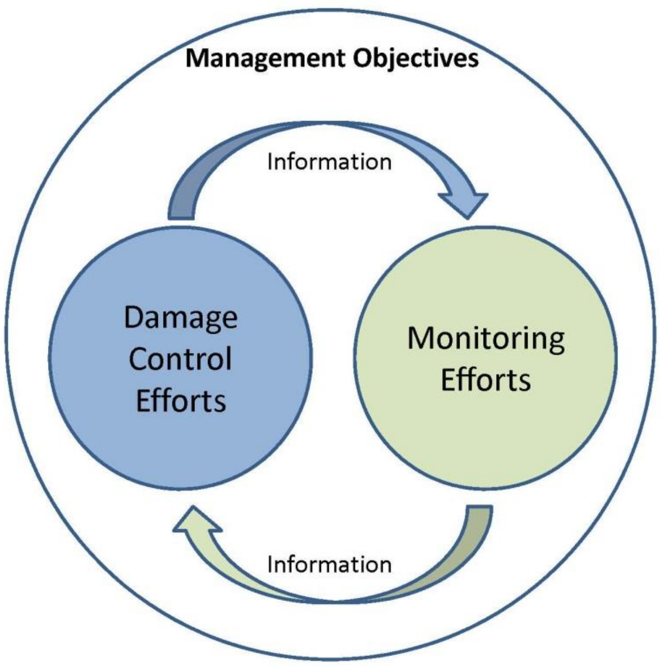


**Figure 36 Pig damage control and monitoring efforts are critical components for achiving management objectives**

Our recommendations are intended to help the Tejon Ranch Conservancy define management objectives, provide an overview of the damage control efforts most likely to be effective on Tejon Ranch for specific habitats, and provide insight into the most cost-effective monitoring regimes.

## 7.1 Recommendation One: Spatially Define Damage Control Efforts

Clearly defining the specific objectives that the Tejon Ranch Conservancy wishes to meet with any pig damage control program is an essential first step. Much of the work of this project has been aimed at providing guidance to inform those objectives. We recommend that the Conservancy utilize this opportunity to clearly define the spaces on the ranch that it wishes to protect. Defining these spatial objectives by habitat type, vegetation cover, presence or absence of priority species, or other important characteristics should result in a map of priority areas to be protected. **Specifically, we recommend that the Conservancy classify primary and secondary priority areas for protection from wild pig damage.** Primary priority areas should be those of highest value in terms of ecological importance that are also at high risk from pig damage. These could include habitats that are essential to sensitive species on the Ranch or that are vital for biodiversity. Secondary habitats should be those that are of high ecological importance, but deemed less important to the overall Ranch ecosystem than priority areas.

The proper pig damage control methods will differ by location given the goals of the Conservancy. Damage control methods vary greatly in terms of both cost effectiveness and the amount of damage that they can eliminate. While the primary goal of wild pig damage efforts on Tejon Ranch should be to reduce disturbance in priority habitats, the acceptable amount of damage within these habitats will dictate the proper damage control efforts. Therefore, once each of the primary and secondary priority areas have been defined, acceptable levels of damage should be defined in terms of the percentage of habitat impacted by pigs. For some sensitive habitats such as wetlands, a complete elimination of damage may be the only "acceptable" level of damage. For other more resilient habitats such as grasslands, current damage levels may be completely acceptable. Recommended control efforts will vary based on the overall goals of the Conservancy for the conserved areas of Tejon Ranch.

## 7.2 Recommendation Two: Monitoring

Based on the findings of our research and case study, we recommend that efforts to monitor wild pigs continue to expand and that they explicitly track wild pig damage. We recommend that the Ranch specifically focus on the collection of data that will inform indices of pig abundance (Monitoring Recommendation 1.1) and pig damage (Monitoring Recommendation 1.2).

### Monitoring Recommendation 1.1- monitoring pig abundance

Pig abundance data can be gathered in collaboration with the Tejon Ranch hunting operation and other wildlife monitoring programs on the Ranch. Based on our review of the hunting program, we believe that data already being collected by the hunting program can be a valuable resource for informing the monitoring effort. Specifically, tracking catch per unit effort in terms of hunter success rates can provide a rough population index for a variety of species (See Section 6.2.1) (Richard A. Lancia, John W. Bishir, Mark C. Conner, & Christopher S. Rosenberry, 1996; Rist, Milner-Gulland, Cowlishaw, & Rowcliffe, 2010).

Modest changes to current information collection, such as tracking hunter effort in terms of days hunted before pig sightings and days hunted before pig harvest, can provide more accurate population indices. These indices can provide important information about pig populations to both the TRC and the Conservancy and can be developed at an extremely low cost. Furthermore, collecting detailed information from hunters such as sighting location, harvest location, and pig demographics can provide valuable input to more advanced population models and can easily be added to current data collection methods (Richard A. Lancia et al., 1996).

We recommend coordinated collection of pig abundance data between the Tejon Ranch Company and the Tejon Ranch Conservancy. We believe that both parties would benefit from improved data collection because both have an interest in understanding pig population trends on the Ranch. In addition to knowing how many pigs are harvested in any given year, the Company would benefit from a better understanding of overall pig abundances and how pig damage levels fluctuate from year to year. As previously mentioned, the Conservancy stands to benefit from understanding the interplay between pig abundance and pig damage in priority habitats.

**We specifically recommend the inclusion of a data sheet about the number of days hunted prior to wild pig observation/harvest be put into the paperwork packet that all hunters receive prior to hunting on the ranch.** This harvest data sheet should include harvested pig sex, age or weight, and the time, date and GPS location of the kill. The location of the pig harvest will help to inform risk to high priority damage areas on the Ranch. Pig demographic information will help to inform the population model being developed by Dr. Kyran Kunkel.

### MONITORING RECOMMENDATION 1.2 – MONITORING PIG DAMAGE

In order to evaluate the relative success of damage control efforts in high priority habitats on the Ranch, we recommend the continuation of the pig damage monitoring program that is detailed in *Chapter Five: Pilot Study*.

Tracking the interplay between pig damage and abundance across different seasons and habitats on Tejon Ranch is a critical component for assessing the effects of wild pig management strategies. The Conservancy will need to establish what the seasonal damage patterns are on the Ranch in order to determine how best to deploy pig control efforts. Many control efforts' effectiveness varies seasonally and optimal deployment requires sophisticated knowledge about the seasonal presence of pig populations. Based on our case study on Tejon Ranch, we recommend a modified method of camera traps and habitat damage surveys (detailed in Chapter 5). The camera trapping component has the added benefit of tracking other wildlife species' abundances on the ranch.

We developed an index of pig activity and rooting damage on the Ranch that can be adapted and combined with other data sources to establish a robust and ongoing monitoring system and demographic population model. Refining these tools will enhance the ability of the Conservancy to track the response of the feral pig population to changes in management practices with minimal cost and effort and will inform overall goals about pig damage reductions.

Our monitoring program included damage assessment in both terrestrial and riparian habitats on the Ranch. We found that riparian damage was correlated with pig presence. Dry conditions prevented us from accurately measuring terrestrial damage. Based on our experience monitoring for pig damage during the dry season in summer 2013, we recommend that initial monitoring efforts be conducted during the winter or spring seasons to increase the likelihood of detecting pig damage as rooting damage is easier seen when the ground is moist. We also recommend that initial monitoring be conducted with a goal of establishing seasonal patterns of pig abundance.

Future monitoring efforts that advance the understanding of pig damage to Tejon Ranch land should be pursued. We recommend enhancing the damage monitoring program to incorporate distance to major water resources, as priority areas become fenced off and pigs potentially become limited by water availability. We believe that tracking the proximity of damage to water is a useful metric that can inform ideal spatial application of pig control efforts.

Our results indicate that it is possible to monitor pig abundance by monitoring one type of pig damage, rooting. Given that the Conservancy is primarily concerned with controlling pig damage, we expect that once damage and abundance correlations have been established throughout the ranch, a greater emphasis can be placed on monitoring pig damage rather than pig abundance.

## 7.3 Recommendation Three: Pig Damage Control Efforts

After reviewing potential pig damage control efforts on Tejon Ranch, we have concluded that the most effective methods are likely to be a mix of hunting, exclusion fencing, and depredation efforts (Figure 37). We compared all of these options through a cost benefit analysis (assumptions are outlined in Appendix 4: Cost Benefit Analysis of Feral Pig Management on Tejon Ranch) and concluded that the method with the highest benefit to cost ratio varied depending on the potential to increase the value of the habitat via damage control.

The use of cost benefit analyses have previously been employed to determine the value of engaging in pig damage control efforts on a single habitat type (Richard M. Engeman et al., 2007). Given the high value of sensitive habitats such as wetlands (King, 1998), and the extent to which pigs can damage these habitats, analyses have often revealed extremely high benefit to cost ratios, even if the control measures are only able to reduce the damage by a small amount (Richard M. Engeman et al., 2007; USDA, 2013).

Pigs are causing damage on Tejon Ranch on numerous land types, each of which has a different habitat value. This means that the most cost-effective damage control technique for a given location is expected to be different than another location with differing habitat values. Given these heterogeneous values of habitats throughout Tejon Ranch, we used our analysis to develop a sense of which control methods would be most cost-effective for varying habitat values across the ranch. We focused our analysis on the three most relevant control methods for Tejon Ranch: hunting, depredation, and exclusion fencing. Given that hunting is expected to be carried out as a continuing Ranch operation no matter which other damage control measures are implemented, hunting is treated as a baseline option that will be supplemented by depredation and fencing, where appropriate.

Estimates for the cost of implementing each control measure were derived from literature and conversations with local experts. We also derived an estimate of both the overall anticipated effectiveness of each control effort and the upper limits of the potential to improve habitat value based on relevant literature. These inputs were used to estimate the overall benefit to cost ratio for each of the control measures at different valued habitats.

Because the overall benefit of each of the measures varies depending on the value of land being protected from pig damage, the benefit to cost ratio changes as a function of the potential to increase the habitat value. We conducted a comparison of each of the control techniques' benefit-to-cost ratios across different valued lands to determine which technique is most appropriate given a potential increase in habitat value. While hunting has the highest benefit to cost ratio at low valued lands, depredation has the highest ratio at intermediately valued lands, and exclusion fencing has the highest ratio at highly valued lands.

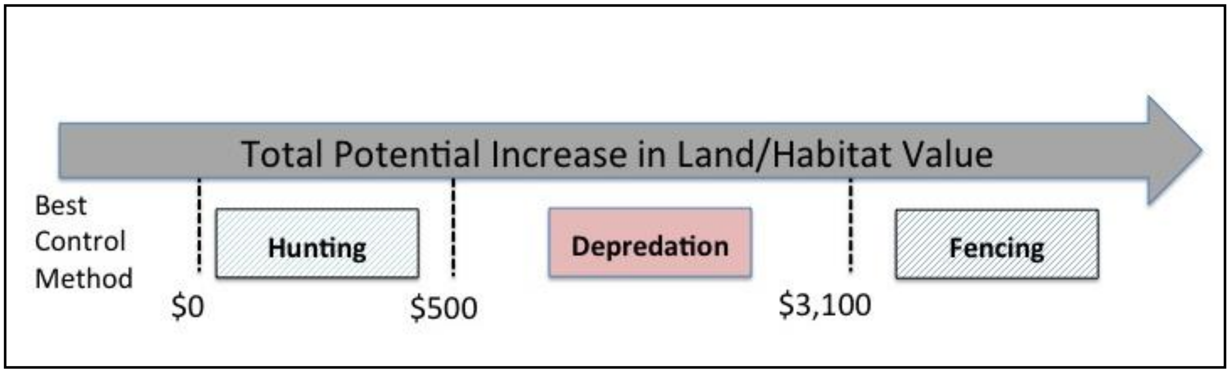


**Figure 37 The damage control effort with the highest benefit to cost ratio is dependent on the underlying potential to increase the habitat value**

## Control Recommendation 3.1 Continuing the Commercial Hunting Program and Increase Targeted Hunting

We recommend that the Conservancy work with the Ranch Company to maintain a sustained, high pig harvest rate through the recreational hunting program into the future. The current hunting program on Tejon Ranch provides an important means of controlling the overall population of pigs on the Ranch. The current harvest goal set by the Company to harvest "as many pigs as possible" in a given year should be the on-going target. The commercial program is highly appealing because it can potentially lower overall pig densities on the Ranch while generating profits for the Company. However, pigs' ability to change behavior and increase fecundity in response to recreational hunting means that recreational hunting should not be considered a stand-alone damage control effort (Hanson et al., 2009b). Rather, recreational hunting should be viewed as a supplementary approach to assist more targeted efforts.

Targeted hunting can be a highly useful management strategy to reduce densities of wild pigs in specific areas and "train" groups to avoid these habitats. While Toigo et al. (2008) found that even intensive recreational hunting pressures were ineffective at controlling pig densities, they concluded that targeting sows and piglets was an important factor in making hunting an effective means of control (Toïgo, Servanty, GAILLARD, Brandt, & Baubet, 2008). While ideal sow and piglet harvest targets are not currently known, this work suggests that a sow and piglet reduction program beyond the simple recreational program currently in place would be an effective means of reducing pig densities.

Other studies have shown that hunting pressure can change the spatial distribution of pigs and push them out of certain areas during the hours in which they are pressured (Keuling, Stier, & Roth, 2008). While this is seen as a negative for hunter success, it can be a positive factor for pig damage control, particularly when a mix of nocturnal and diurnal pressures are applied. We recommend that targeted hunting include a focus on sows and piglets for harvest and applying consistent hunting pressure, including night hunting, to high priority habitats.

Furthermore, securing depredation permits will expand the potential applications of targeted hunting to include night hunting and more efficient weaponry. For the purposes of our cost benefit analysis, the recreational hunting program was treated as a baseline condition that would exist regardless of other damage control efforts. Targeted hunting options were considered part of the depredation efforts. Using the assumptions outlined in Appendix 4: Cost Benefit Analysis of Feral Pig Management on Tejon Ranch, the recreational hunting program has the highest benefit to cost ratio of all control methods on lands whose habitat value can be increased up to $500 per acre.

## Control Recommendation 3.2 Pig Exclusion

A key component of our recommended management strategy is to exclude pigs from high priority habitats by erecting pig proof fencing. Fencing out pigs is the most effective direct damage control option for eliminating pig damage. Fencing is extremely targeted and allows property owners to choose the exact locations from which they wish to exclude pig populations. The cost of installing and maintaining fencing is quite high, and fencing can impede the movement of wildlife species and cattle across the Ranch. However, fencing is, by far, the most effective means of limiting pig damage.  Our cost benefit analysis indicates that fencing offers the greatest benefit-cost ratio in areas of high ecological or economic value. Using the assumptions outlined in Appendix 4: Cost Benefit Analysis of Feral Pig Management on Tejon Ranch, **we recommend that fencing be utilized as the damage control technique on any land where control efforts could result in an increase in habitat value greater than or equal to $3,100 per acre**.

We recommend that the Tejon Ranch Conservancy engage in a collective effort to determine those areas that are of greatest need for protection from pig damage and that they erect pig proof fencing in those locations and remove pigs from within the exclosures.  Electrifying fences maybe appropriate for extremely small areas that are easily maintained, however standard, non-electric fences will be most appropriate for the vast majority of exclusions. Current cattle operations require that this fencing also be able to withstand pressure from cattle. While this option can be expensive, it also has the greatest chance for long-term success

## Control Recommendation 3.3 Depredation

Utilizing depredation permits is a key tool and we recommend that it should be part of population control efforts on the ranch for priority areas. As discussed in Chapter 6, the Conservancy has a clear path forward in terms of working with the Company in order to secure further depredation permits throughout the Ranch, specifically on high priority habitats that are not appropriate for fencing due to location or cost of installation. Depredation permits allow for cost effective control methods and significantly expand the Conservancy's options for controlling pigs such as night hunting and trapping.

Once a permit is secured, the Ranch can seek subsidized assistance for its depredation efforts through the USDA's Wildlife Services. Wildlife Service can be listed as an agent on a depredation tag and they bring access to resources and more sophisticated control means, such as automatic weapons and a large base of knowledge for implementing control techniques.

We caution that the depredation process has numerous uncertainties for implementation and can take years to refine down to an efficient control mechanism. Specifically, depredation success is often times limited by seasonal movements and diets, as well as geographic location (Caley, 1994). Local knowledge of pig movements and diets improves the chance of success for trapping requires knowledge about what baits will consistently attract pigs. Figuring out the most efficient schedule for implementing trapping and night hunting can take time, and should be informed by monitoring efforts.

The most efficient depredation efforts will likely be a combination of trapping and night hunting. While trapping has proven to be an extremely cost effective pig population control technique in other settings, it is only effective during specific times of the year when pigs are present in an area. Trapping efforts are ideally shifted throughout the year to focus on areas where pigs are the most destructive to priority habitats. As such, seasonal movements will need to be informed by pig damage monitoring efforts. **We recommend that Tejon Conservancy engage in a trial period of depredation efforts in priority areas that are unfenced to better understand which techniques work in which habitats at which times of the year. Once spatial damage patterns are understood, an expansion of systematic trapping and night hunting efforts should begin.**

Using assumptions outlined in Appendix 4: Cost Benefit Analysis of Feral Pig Management on Tejon Ranch, Our cost benefit analysis showed that depredation efforts had the highest benefit cost ratio among control efforts at lands where habitat value could be increased between $500 and $3,100 per acre by engaging in pig damage control efforts.

### *Control Efforts in Conjunction with Tejon Ranch Company*

Controlling pig damage on Tejon Ranch is likely to involve increased lethal removal of pigs. Given the legal framework within which pigs are managed in California, the landowner, in this case the Tejon Ranch Company, will need to be involved. Communicating the economic losses that the Ranch Company currently suffers and is at risk of suffering is an important consideration. The cost benefit analysis that was conducted based on habitat quality is equally relevant for the economic value of lands and could be employed by the Company in their evaluation of pig control. High value lands such as the agriculture and residential developments are likely to warrant some additional level of damage control above the current hunting program, especially given that hunting is prohibited around agriculture and residential portions of the ranch. Given pigs ability to quickly migrate from one portion of the ranch to another in response to management actions, it will be important for the Company and the Conservancy to coordinate damage control efforts.

## 7.4 Recommendation Four: Pig Action Network

As was discussed in Chapter 2, wild pigs have continued to spread throughout California over the last forty years (Figure 38) without respect to county lines or property boundaries. In the oak woodlands of California's Sierra foothills, pigs have been shown to increase their home ranges by 5-8 km$^2$ annually (Barrett 1978). Wild pigs have also been shown to respond to population control efforts by increasing migration from surrounding lands (Sparklin, Mitchell, Hanson, Jolley, & Ditchkoff, 2009). These invasions can be driven by resource availability, but they can also be responses to pressures such as hunting and depredation. As such, the actions that any single landowner or manager take to control pigs on his or her land does not occur within a vacuum, and even the best pig control efforts can be undermined by the inactivity of one's neighbors. Conducting simultaneous wild pig control

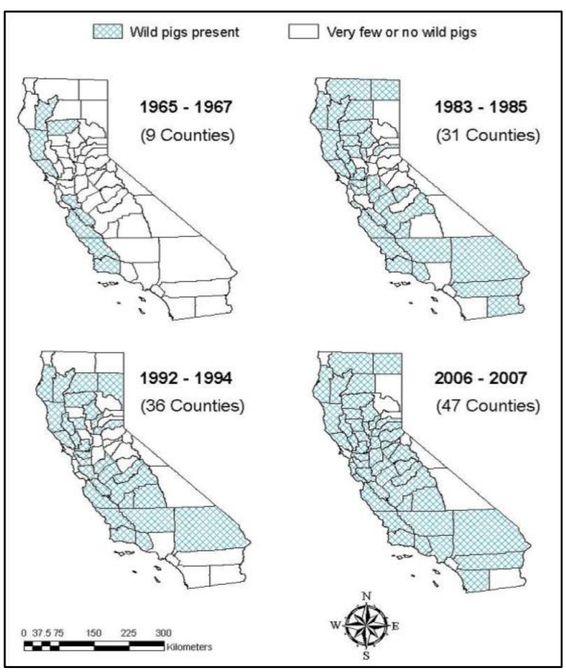


**Figure 38 Presence of wild pigs throughout California (Sweitzer and McCann, 2007)**

across a landscape, rather than just on individual properties, has the potential to increase the effectiveness of any single landowners' control program.

To that end, we recommend that the Tejon Ranch Conservancy form a regional network of Central Valley landowners, land managers, and land users to enhance collaboration among stakeholders who are impacted, or potentially impacted, by invasive wild pigs. The inspiration for this new regional networking-based management tool, preliminarily dubbed the Pig Action Network or PAN, draws on other current regional conservation organizations such as the Stewardship Network, which helps "connect, equip, and mobilize individuals, organizations, and businesses through community conservation collaboratives" (Stewardship Network, 2007).

**Guiding goals for PAN could include:**

1) Disseminating information to Central Valley communities about wild pigs and the types of economic and ecological damage associated with them
2) Coordinating a regional wild pig control program targeting travel routes, refuge areas, and known hot spots of pig activity
3) Exchanging management "lessons learned" among land managers and landowners in the region and sharing relevant data
4) Promoting restoration techniques of wild pig degraded ecosystems in the future
5) Supporting stakeholder participation as a means of strengthening governance and responsible decision-making
6) Building support for lobbying efforts to change the CDFW classification of wild pigs in California from "big game" to "pest."

Coordinating wild pig management on a regional scale could help prevent lands adjacent to Tejon Ranch from becoming refuges for pigs escaping from any hunting or depredation activity occurring on the Ranch. It could also help to prevent re-invasion of the Ranch during periods of low hunting or depredation activity, and it could lead to a more effective, overall reduction of wild pig abundances and thus damage in the region. Also, simply building an awareness of the types and extent of damage caused by pigs in the larger area could help increase support for changing how wild pigs are managed at the state level, specifically changing the status of pigs from a game species to a pest species in order to give landowners more autonomy and options for controlling wild pig populations on their lands.

It is important to note that the time for such statewide changes may be particularly ripe for several reasons. First, while hunting has been historically important to the state of California, there has been an overall decline in the total number of hunting tags sold over the last twenty years. Indeed, US Fish and Wildlife data on the number of licensed hunters in California shows a 51% decline in the number hunters in the state between 1978 and 2013 (US Fish and Wildlife Service, 2013). In contrast, during the last 20 years California has witnessed an astronomical growth in the value of the state's agriculture industry, which more than doubled in value (Figure 39). As has been extensively discussed elsewhere in the report, wild pigs pose a particular threat to a number of different high-value agricultural operations found throughout the Central Valley. In California, it is likely that the approximately $1 million in revenue from wild pig tags for CDFW does not begin to outweigh the actual cost of damages that pigs cause to agricultural lands, ecologically important lands, and developed lands. Even when the wild pig hunting industry is considered as a whole, there are serious doubts about whether the numbers can even come close to matching agricultural losses.

Second, as noted earlier, several other states in the country, including North Carolina and Tennessee, have recently successfully changed their classification of wild pigs from game species to pest species in response to concerns over the types of economic and ecological damage pigs can do.

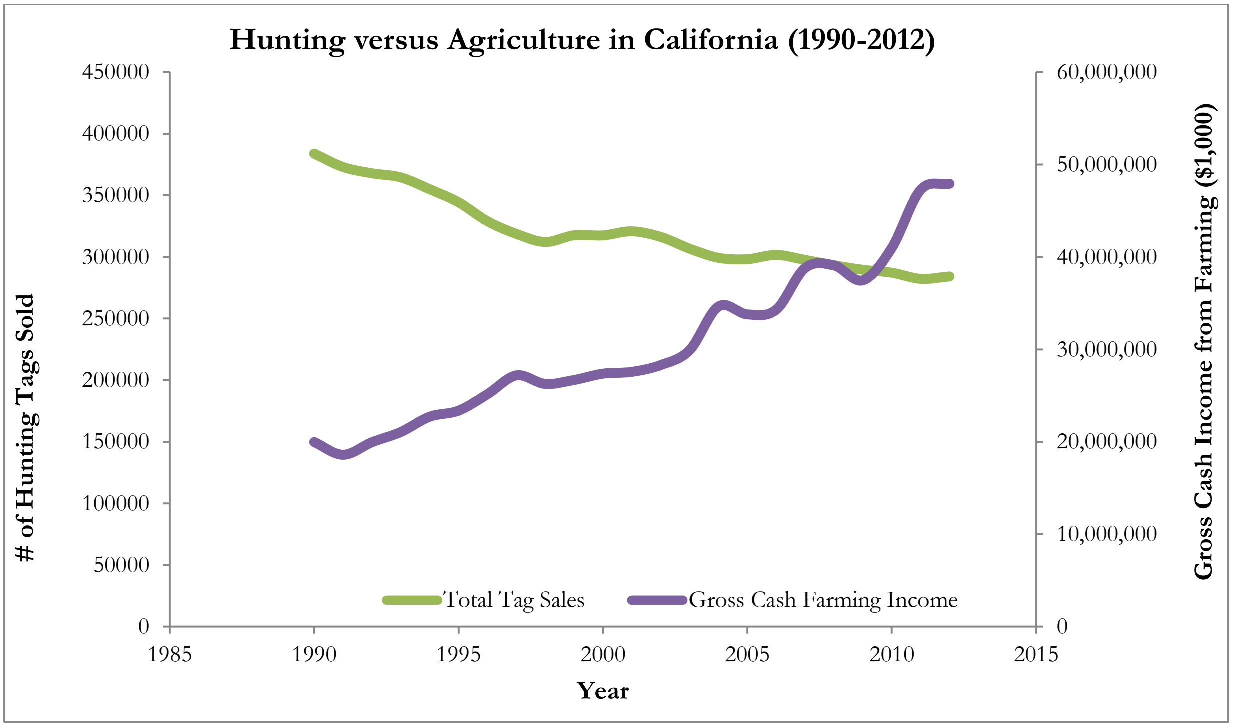


**Figure 39 Comparing trends in agriculture and hunting, based on gross income from farming and total number of tags sold respectively, over the last twenty years. Note the differences in scale between the two vertical axes.**

PAN potentially presents a partial solution to the spread of pig populations and their accompanying impacts via collaboration, information sharing regarding effective management techniques, and a consolidated interest group that can push for legislative change. With the power of a regional network, PAN can facilitate community and coalition building among land users of the Central Valley who may not have the means to engage in pig management strategies otherwise. Various potential participants are listed in Table 8 below.

**Table 8 Potential Participants in the Pig Action Network**

| Organization | Contact |
|---|---|
| Tejon Ranch Conservancy | Michael White or Scot Pipkin |
| Los Padres National Forest | Justin Haley |
| Edwards Air Force Base | Mark Bratton |
| Hungry Valley SVRA | Chris Hon |
| Sequoia National Forest | Supervisors Office (559.784.1500) |
| Angeles National Forest | (626) 574-1613 |

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# APPENDIX

## APPENDIX 1: WILD PIG SURVEY FOR HUNTERS AND GUIDES

Bren School of Environmental Science & Management
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

Thank you for participating in this survey. Your local knowledge and hunting experience at Tejon Ranch is requested to contribute to a study of wild pigs by Master's students from the Bren School of Environmental Science & Management at UCSB and the Tejon Ranch Conservancy. Your answers are important and will increase our understanding of wild pig presence and harvest on the ranch. This information will help contribute to the hunting program at Tejon Ranch.

The survey should only take about 10 minutes to complete. This is an entirely anonymous and voluntary survey and your individual responses will be kept strictly confidential. If you have questions or would like a copy of the results, please contact us at the address on the last page of this survey. Thank you.

**If possible, please take this survey online at**

---

1. In which state are you a resident? _____
2. How many years in total have you hunted pigs in California? _____
3. How many of the last 5 years did you hunt pigs in California? _____

   Have you hunted pigs anywhere else in California? _____YES _____NO

   If yes, where?____________________________________________

4. Have you hunted pigs in any other state? _____YES _____NO

   If yes, where?____________________________________________

5. In the last five years, what kind of land have you hunted pigs on?(check all that apply)

   _____PUBLIC _____PRIVATE

6. How has your interest in pig hunting in California changed in the last 5 years?

   _____Less interested _____No Change _____More Interested

7. ***On Tejon Ranch***, how many boars, sows, and piglets did you harvest in the last year? (please write 0 if none were harvested)
   _____ Boars _____ Sows _____ Piglets
8. ***In California, excluding Tejon Ranch***, how many boars, sows, and piglets did you harvest in the last year? (please write 0 if none were harvested)

   _____ Boars _____ Sows _____ Piglets

9. ***In all other states***, how many boars, sows, and piglets did you harvest in the last year?

(please write 0 if none were harvested)
_____ Boars _____ Sows _____ Piglets

10. Which type of pig hunt/s did you participate in at Tejon Ranch during the last year?

_____Guided Pig Weekday _____Guided Pig Weekend

_____Wild Pig Management Hunt _____Unguided Hunt

11. Considering the current population of wild pigs at Tejon Ranch, how has the population changed?

Compared to last year: _____LOWER _____SAME _____HIGHER _____UNSURE

Compared to 3 years ago: _____LOWER _____SAME _____HIGHER _____UNSURE

Compared to 5 years ago: _____LOWER _____SAME _____HIGHER _____UNSURE

12. In your opionion, is the wild pig population at Tejon Ranch:

_____ Too Large _____ About Right _____ Too Small

13. Do you donate any of the pig meat that you harvest? _____YES _____NO

If YES, where do you donate the meat? (ie, foodbank, church, etc.) Please be specific.
_______________________________________________________________

14. If there were a reliable outlet available for donations of meat would you hunt more?

_____YES _____NO _____Unsure

15. Which type of hunting membership do you have?

_____Fall Hunting _____Summer Program _____ Cross & Crescent _____None

Indicate how strongly you agree or disagree with each statement by **circling one number** on each row.

| | Strongly Disagree | Disagree | Unsure | Agree | Strongly Agree |
|---|---|---|---|---|---|
| Wild pigs are native to California. | 1 | 2 | 3 | 4 | 5 |
| Wild pigs are a welcome addition to the number of big game species I can hunt | 1 | 2 | 3 | 4 | 5 |
| I only hunt for boars. | 1 | 2 | 3 | 4 | 5 |
| I worry about problems wild pigs might cause Tejon Ranch. | 1 | 2 | 3 | 4 | 5 |
| I worry about problems wild pigs might cause in greater California. | 1 | 2 | 3 | 4 | 5 |
| Wild pigs are a source of disease. | 1 | 2 | 3 | 4 | 5 |
| Wild pigs detract from hunting other game. | 1 | 2 | 3 | 4 | 5 |

| | | | | | |
|---|---|---|---|---|---|
| Hunting can stabalize wild pig populations. | 1 | 2 | 3 | 4 | 5 |
| Trapping and culling should be used to help control wild pigs. | 1 | 2 | 3 | 4 | 5 |
| I would hunt sows or piglets to help manage pig populations. | 1 | 2 | 3 | 4 | 5 |

Indicate how strongly you agree or disagree with each statement by **circling one number** on each row.

| | Strongly Disagree | Disagree | Unsure | Agree | Strongly Agree |
|---|---|---|---|---|---|
| *Wild pigs should be managed primarily for…* | | | | | |
| a healthy ecosystem. | 1 | 2 | 3 | 4 | 5 |
| a healthy pig population. | 1 | 2 | 3 | 4 | 5 |
| minimizing damage from pigs. | 1 | 2 | 3 | 4 | 5 |
| *I would accept lower pig populations and seeing fewer pigs when hunting, if necessary to...* | | | | | |
| increase the size of boars. | 1 | 2 | 3 | 4 | 5 |
| increase numbers of other game. | 1 | 2 | 3 | 4 | 5 |
| improve habitat quality. | 1 | 2 | 3 | 4 | 5 |
| reduce damage from pigs. | 1 | 2 | 3 | 4 | 5 |
| *I am completely satisfied with …* | | | | | |
| wild pig hunting seasons and hunt options at Tejon Ranch. | 1 | 2 | 3 | 4 | 5 |
| rules for hunting wild pigs at Tejon Ranch. | 1 | 2 | 3 | 4 | 5 |
| the price of my hunt. | 1 | 2 | 3 | 4 | 5 |
| the number of boars seen. | 1 | 2 | 3 | 4 | 5 |
| the size of boars seen. | 1 | 2 | 3 | 4 | 5 |

Please provide any additional comments, observations, details, or questions in the space provided below.

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS SURVEY.
PLEASE RETURN THIS SURVEY IN THE POSTAGE PAID ENVELOPE PROVIDED.
THIS SURVEY HAS UNDERGONE REVIEW FROM THE UCSB OFFICE OF RESEARCH HUMAN SUBJECTS COMMITTEE (805-893-4188). IF YOU HAVE QUESTIONS OR IF YOU WOULD LIKE A COPY OF THE RESULTS OF THIS SURVEY, PLEASE CONTACT:

Adam T. Kreger
Survey Contact
Bren School of Environmental Science & Management
University of California, Santa Barbara
Phone: 952.240.9377
Email: chanchos@lists.bren.ucsb.edu

# APPENDIX 2: FERAL PIG SURVEY FOR LAND OWNERS AND LESSEES

Bren School of Environmental Science & Management
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

Thank you for participating in this survey. Your local knowledge is requested to contribute to a study of feral pigs by Master's students from the Bren School of Environmental Science & Management at UCSB. Your answers are important and will increase our understanding of feral pig presence, impacts, and management in California. This information will help us develop more effective management strategies for feral pigs.

The survey should only take about 20 minutes to complete. This is an entirely anonymous and voluntary survey and your individual responses will be kept strictly confidential. If you have questions or would like a copy of the results, please contact us at the address on the last page of this survey. Thank you.

**If possible, please take this survey online at** https://survey.insightify.com/4eb-3c4-661-5e2**.**

16. In what county and zip code do you own/lease land?___________________________________________
17. What is the approximate acreage of your land?________________________________________________
18. How many years have you owned, leased or managed this land? ______ Years
19. What is the **Primary** use for this land? (Please select one)

    ____ Hunting ____ Recreation (non-hunting) ____ Timber Production ____ Conservation

    ____ Livestock Production (Please list animals)_________________________________________________

    ____ Crop Production (Please list crops)_________________________________________________

    Other/Mixed Use (Please specify)

    _____________________________________________________________

20. Are feral pigs present on your land? _____YES _____NO _____UNSURE
    (If **YES or UNSURE**, please continue below. If **NO**, please skip ahead to Question **33**.)
21. When did you first notice feral pigs or feral pigs sign on this property?

    __________Year __________Month

22. How many feral pigs have been seen on your land in the last year? _______________
23. Do you hunt/shoot feral pigs on your land? _____YES _____NO
24. Do you allow others to hunt/shoot feral pigs on your land? _____YES _____NO
25. How many feral pigs have been killed on your land in the last year? _______________

26. Before you received this survey, did you know that feral pigs could be a problem for landowners or lessees? Please circle one. _____YES _____NO

27. Have feral pigs ever damaged your land or property? _____YES _____NO
(IF **YES**, please continue below. IF **NO,** please skip ahead to question **29**.)

28. During the last year, what types of damage have you had? (Please select **ALL** that apply.)

________ Damage to cash crop

________ Damage to waterways

________ Damage or injury to pets

________ Damage or loss of livestock feed

________ Damage to pastures

________ Damage to vineyards

________ Landscape damage (e.g. yard, etc.)

________ Loss of land value

________ Wallows

___________ Damage to wildlife habitat

___________ Damage to other water sources

___________ Damage or injury to livestock

___________ Damage to rangeland

___________ Damage to fences

___________ Damage to equipment

___________ Loss to timber

__________ Loss of lease value

__________ Rooting or grubbing

________ Other (please specify)________________________________________________

29. From the list above, please tell us the **ONE** type of damage that was most important to you.

______________________________________________________________________

30. The type of damage caused by feral pigs is viewed differently between landowners. The importance of that damage also differs. In Question 13 above, you told us which type of damage was **MOST IMPORTANT** to you. How do you define importance?

______ Cost me the most money

______ Changed the appearance of the land in a bad way

______ Negatively impacted how I use the land

______ Other (please explain)________________________________________________

31. Considering the current population of feral pigs on this land, how has the population changed in the following time spans? (Please circle one answer in each row)

Compared to last year: _____LOWER _____SAME _____HIGHER _____UNSURE

Compared to 3 years ago: _____LOWER _____SAME _____HIGHER _____UNSURE

Compared to 5 years ago: _____LOWER _____SAME _____HIGHER _____UNSURE

32. Did you seek outside help to reduce pig numbers on your land?_____YES _____NO

33. If YES, please tell us who you contacted. (select all that apply)

____ California Department of Fish and Wildlife

____ USDA Wildlife Services

____ Landowner

____ Private animal control company

Other (Please list) ____________________________________________________________

34. What was the nature of the help? (select all that apply)

_____ Killing ____Trapping and Relocation

_____ Fencing ____Other (please specify) __________________ ______

35. Did this outside help reduce the damage? _____YES _____NO _____UNSURE

36. Would you seek outside help again from this source? _____YES _____NO _____UNSURE

37. Would you seek help from another source? _____YES _____NO _____UNSURE

38. What do you think is the main cause of increases in feral pig populations? (Please check all that apply.)

_____ Neighbor's management practices _____ Lack of hunting pressure

_____ Natural causes _____ Other (please specify)_________________________

39. In the last year, which **LETHAL** control measures have you used to control feral pigs on this property?

____Opportunistic Hunting _____ Trapping ____ Dog hunting ____ None

____Other (please specify)________________________________________________________________

40. Which lethal method did you find most effective? ____________________________________________

41. Which lethal method did you find least effective? ____________________________________________

42. In the last year, which **NON-LETHAL** control measures have you used to control feral pigs on this property?

____ Electric Fencing ____ Harassment _____ Repellent

____ Non-Electric Fencing ____ None

____Other (please specify)________________________________________________________________

43. Which non-lethal method did you find most effective? ________________________________________

44. Which non-lethal method did you find least effective? ________________________________________

45. Estimate your losses to crops and/or crop related damage caused by feral pigs during the last year.

$_________________.00

46. Estimate your losses to non-crop related damage caused by feral pigs during the last year (i.e. fences, water systems, etc).

$_________________.00

47. Approximately how much have you spent on control of feral pigs on your property during the last year?

$_________________.00

48. Based on your experience, who **currently offers** assistance for feral pig management on private lands?

_____________________________________________________________________________________

49. Based on your experience, who **should be** offering assistance for feral pig management in your area?

_______________________________________________________________________________________

Please indicate how strongly you agree or disagree with the following statements about feral pigs by **circling one number** on each row.

| | Strongly Disagree | Disagree | Unsure | Agree | Strongly Agree |
|---|---|---|---|---|---|
| *Feral pigs should be managed for…* | | | | | |
| a healthy ecosystem. | 1 | 2 | 3 | 4 | 5 |
| a healthy pig population. | 1 | 2 | 3 | 4 | 5 |
| minimizing damages. | 1 | 2 | 3 | 4 | 5 |
| I enjoy seeing feral pigs around my property. | 1 | 2 | 3 | 4 | 5 |
| Feral pigs are an important part of the environment. | 1 | 2 | 3 | 4 | 5 |
| Feral pigs are native to California. | 1 | 2 | 3 | 4 | 5 |
| I worry about problems feral pigs might cause to my property. | 1 | 2 | 3 | 4 | 5 |
| Feral pigs are a nuisance. | 1 | 2 | 3 | 4 | 5 |
| Feral pigs are a source of disease. | 1 | 2 | 3 | 4 | 5 |
| Feral pigs should be eliminated whenever possible. | 1 | 2 | 3 | 4 | 5 |
| Feral pigs are a threat to the safety of people. | 1 | 2 | 3 | 4 | 5 |
| Feral pigs have a negative impact on local wildlife populations. | 1 | 2 | 3 | 4 | 5 |
| Increasing hunting pressure can control feral pig numbers. | 1 | 2 | 3 | 4 | 5 |
| Trapping and culling | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| should be used to help control pig numbers. | 1 | 2 | 3 | 4 | 5 |

| | Strongly Disagree | Disagree | Unsure | Agree | Strongly Agree |
|---|---|---|---|---|---|
| Dog hunting for feral pigs should be allowed. | 1 | 2 | 3 | 4 | 5 |
| I would kill sows or piglets to help control pig numbers. | 1 | 2 | 3 | 4 | 5 |

Please provide any additional comments, observations, details, or questions in the space provided below.

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS SURVEY.
PLEASE RETURN THIS SURVEY IN THE POSTAGE PAID ENVELOPE PROVIDED.
THIS SURVEY HAS UNDERGONE REVIEW FROM THE UCSB OFFICE OF RESEARCH HUMAN SUBJECTS COMMITTEE (805-893-4188). IF YOU HAVE QUESTIONS OR IF YOU WOULD LIKE A COPY OF THE RESULTS OF THIS SURVEY, PLEASE CONTACT:

Adam T. Kreger
Survey Contact
Bren School of Environmental Science & Management
University of California, Santa Barbara
Phone: 717.991.0252
Email: tejonchanchos@lists.bren.ucsb.edu

# APPENDIX 3: WILD PIG POPULATION MODEL

## ABSTRACT

In California, and across the United States, wild pigs (*Sus scrofa*) are harmful invasive species which destroy habitat, spread disease, and eat almost anything. Wild pigs have high fecundity, birthing an average litter size of five piglets every year (Barrett, 1978). As a result, they are an important and challenging invasive species to manage. This project created a single-species stage structured population model for wild pigs. The model will follow a similar approach to Fujiwara and Caswell (2001) by creating a transition model, focused on different stages of female pigs. In the analysis, elasticities were examined to identify the stage that is most sensitive to management. Reductions in population densities at different stages were also examined to determine the effects of targeted culling in different stages on population size.

## INTRODUCTION

In California, and across the United States, wild pigs (*Sus scrofa*) are harmful invasive species which destroy habitat, spread disease, and eat almost anything. Wild pigs have high fecundity, birthing an average litter size of five piglets every year, and producing up to two litters every three years (Barrett, 1978). Average lifespan of wild pigs is estimated to be between three and five years, with sexual maturity occurring as early as six months, but more commonly after the first year (Baber and Coblentz, 1986). As a result, they are an important and challenging invasive species to manage. Wild pigs are also known for their intelligence and quick responses to management actions (Barrett, 1978), which can further affect their persistence and spatial distributions.

This project examines the population dynamics of wild pigs and examines different management regimes and culling pressures for a theoretical wild pig population without environmental stochasticity or carrying capacity.  A matrix model was used to create a stage structured population model to examine population growth rate. The model will be used to determine which stage is the most influential on the long term growth rate of the total population. Following model creation, I will then examine the effect of reducing survival in different stage classes in order to examine its effect on long term population growth.

## MODEL

Using a literature review to determine survival rates at different stages and fecundities, a matrix model was created with three separate stages of female wild pigs. Because boars are typically solitary and do not aid in the survival of piglets, this model represents female populations. Stages are defined as the piglet stage (0-1 year), yearling stage (1-2 years), and the adult stage (2+ years). There is a different probability of surviving from one stage to the next as well as a different probability of staying in that stage. Fecundities from the yearling and adult stages were also included. Figure 1 illustrates each of these stages and the variables representing the probabilities and fecudities associated with each stage or change in stage.

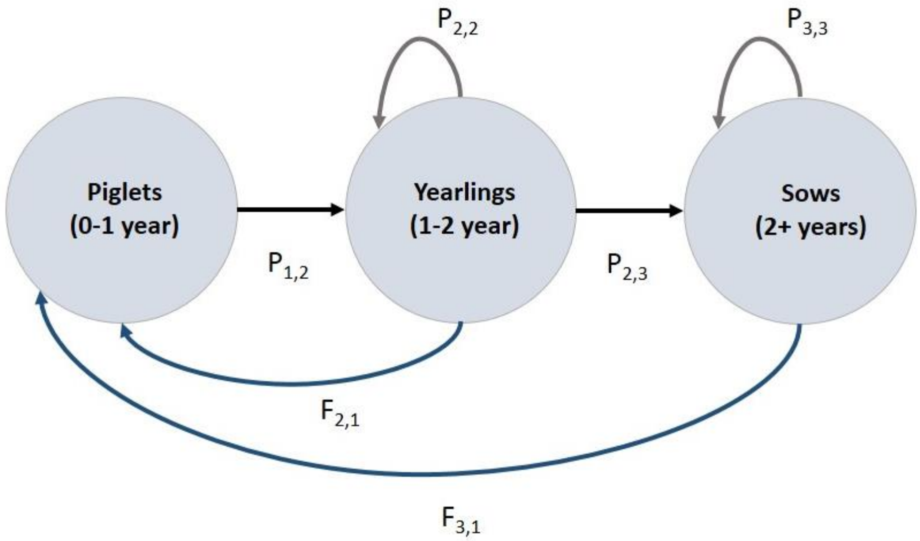


**Figure 1: Conceptual diagram of stage structured model of wild pig population growth. P's represent the probability of moving from one stage to another or staying in the same stage. F's represent fecudities from the yearling and sow stages.**

Probabilities of survival and fecudities were estimated from the literature and are listed below:

$P_{1,2}$ : probability the piglet will become an yearling (0.42 $year^{-1}$) (Baber and Coblentz, 1986)

$P_{2,2}$: probability a yearling will survive and stay in that stage (0.56 $year^{-1}$) (Gabor, 1999)

$P_{2,3}$: probability the yearling will become an adult (0.56 $year^{-1}$) (Gabor, 1999)

$P_{3,3}$: Survival of the adult stage (0.56 $year^{-1}$) (Gabor, 1999)

$F_{2,1}$: Fecundity of yearlings (1.72 $year^{-1}$) (Taylor, 1998)

$F_{3,1}$: Fecundity of adults (4.55 $year^{-1}$) (Taylor, 1998)

These values are then put into a matrix model to determine long term growth rates (Figure 2). For this exercise, it is assumed that the probability of survival in the yearling and adult stages is the same, therefore the probability of surviving from the yearling to the adult stages is also the same.

$$L = \begin{bmatrix} 0 & F_{2,1} & F_{3,1} \\ P_{1,2} & P_{2,2} & 0 \\ 0 & P_{2,3} & P_{3,3} \end{bmatrix} = \begin{bmatrix} 0 & 1.72 & 4.55 \\ 0.42 & 0.56 & 0 \\ 0 & 0.56 & 0.56 \end{bmatrix}$$

**Figure 2: 3x3 Matrix model for three stage wild pig population model.**

This matrix model was modeled into RStudio 3.0.3 to determine long term population growth over a ten year period using the 'popbio' package. For this exercise, assumed a theoretical population of 50 adult females, 50 adult yearling females, and 175 female piglets was assumed. Sex ratios in wild pigs are seen to be approximately 1:1 in California (Baber and Coblentz, 1986), and the California average litter size of five piglets per adult female (Barrett, 1978) was used. Therefore, assuming an initial piglet population of 250 piglets, 175 female piglets would be expected. Projections for each stage were then plotted and the stable stage and elasticities were calculated using the 'popbio' package.

After determining which stage was most influential in determining long term growth, the probability of that stage was reduced by half. The same tests were carried out with the 'popbio' package. This was also done with the second most influential stage. This is discussed further in the results section below.

## RESULTS

### INITIAL CONDITIONS

For the initial population, using values from the literature, we found that the ten year projected population size to be 21,765 piglets, 8590 yearlings, and 4521 adults, for a total of 34,876 pigs (Figure 3). The stable stage for the piglet population was estimated to be 0.62, 0.25 for yearlings, ad 0.13 for adults. Lambda is estimated to be 1.62 for this population. Elasticities are listed in table 1 below.

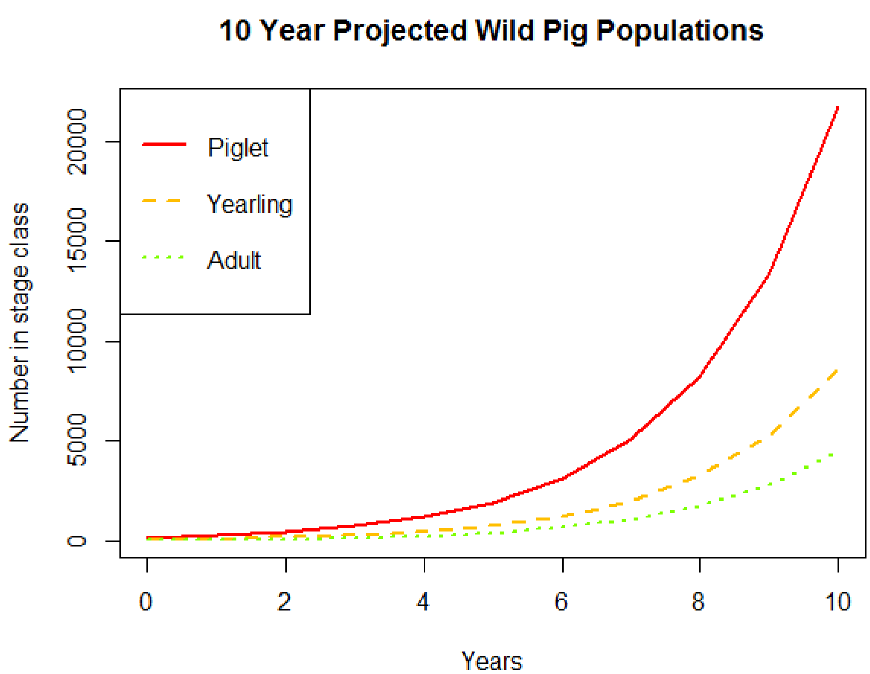


**Figure 3: Ten year project wild pig population for an initial population of 50 adults, 50 yearlings, and 175 piglets.**

| | Piglets | Yearlings | Adults |
|---|---|---|---|
| Piglets | 0.0000 | 0.1224 | 0.1704 |
| Yearlings | 0.2929 | 0.1541 | 0.0000 |
| Adults | 0.0000 | 0.1704 | 0.0897 |

**Table 1: Elasticities showing the relative influences of each stage on the long term growth of the population.**

From the elasticities we determined that the piglet to yearling ($P_{1,2}$) to be the most influential on the long term growth. The yearling to adult ($P_{2,3}$) is the second most influential in determining the long term size of the population. Each of these probabilities were halved in order to examine the effects of culling in different stages.

## CULLING IN THE PIGLET STAGE

When we divide the survival rate of piglets into the yearling stage ($P_{1,2} = 0.21$), we see a reduction in the total population, which is reduced to 5608 individuals (Figure 4). There are reductions across stages, with final populations projected to be 3836 piglets, 1032 yearlings, and 740 adults. Lambda is estimated to be 1.34, so we see a decline in growth rate at the stable stage. The stable stage distribution is estimated to be 0.68 for the piglet class, 0.18 for the yearling class, and 0.13 for the adult class. Elasticities are shown in Table 2.

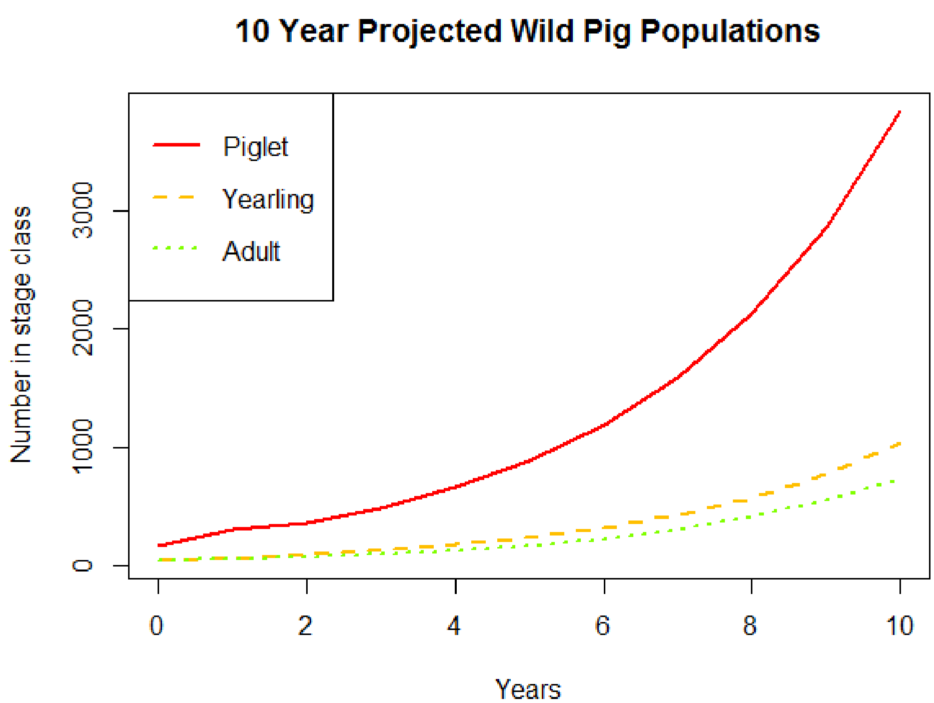


**Figure 4: Ten year project wild pig population for an initial population of 50 adults, 50 yearlings, and 175 piglets, with a reduced survival rate of the piglet to yearling class ($P_{12} = 0.21$).**

| | Piglets | Yearlings | Adults |
|---|---|---|---|
| Piglets | 0.0000 | 0.0898 | 0.1704 |
| Yearlings | 0.2603 | 0.1867 | 0.0000 |
| Adults | 0.0000 | 0.1705 | 0.1223 |

**Table 2: Elasticities showing the relative influences of each stage on the long term growth of the population with a reduced survival rate of the piglet to yearling class ($P_{12} = 0.21$). We see that the piglet to yearling class still remains the most important class, however the yearling stage becomes more important than in the initial simulation.**

## CULLING IN THE YEARLING STAGE

When the survival rate of the yearling to adult class is reduced by half ($P_{2,3}$=0.28), the population size is not reduced as significantly, but we still see a reduction to 8609 individuals (Figure 5). Across the stages, we see a reduction in each stage with populations of 5323, 2633, and 653 individuals for the piglet, yearling, and adult stages respectively. The stable stage distribution is estimated to be 0.62, 0.31, and 0.08 for the piglet, yearling, and adult stages with a lambda of 1.41. Elasticities are listed in Table 3.

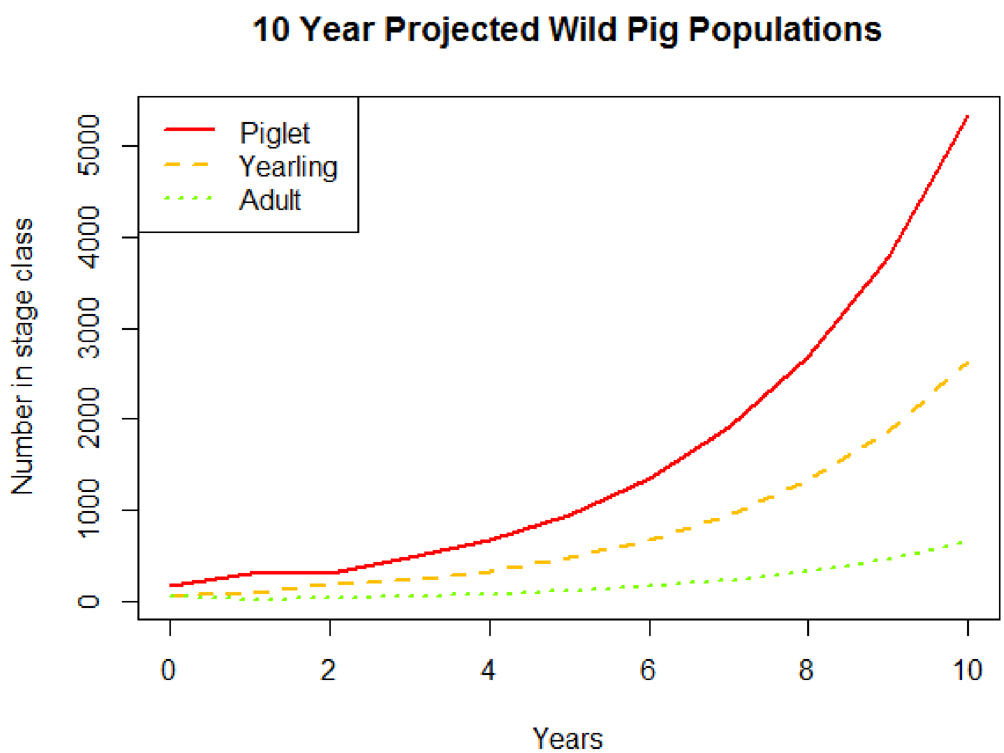


**Figure 5: Ten year project wild pig population for an initial population of 50 adults, 50 yearlings, and 175 piglets, with a reduced survival rate of the yearling to adult class ($P_{12}$ = 0.28).**

| | Piglets | Yearlings | Adults |
|---|---|---|---|
| Piglets | 0.0000 | 0.1915 | 0.1256 |
| Yearlings | 0.3171 | 0.2091 | 0.0000 |
| Adults | 0.0000 | 0.1256 | 0.0311 |

**Table 3: Elasticities showing the relative influences of each stage on the long term growth of the population with a reduced survival rate of the yearling to adult class ($P_{23}$ = 0.28). We see that the piglet to yearling class still becomes even more important, and the yearling stage becomes more important than in the initial simulation.**

## CONCLUSIONS AND DISCUSSION

In the initial simulation, the population grows at a rate of 62% per year (lambda = 1.62), when the population is at the stable stage. This initial run also reveals that the transition from piglets to yearlings is the most important in determining the total growth of the population (elasticity = 0.2929). After simulating that half the piglet population survives (representing an increase in mortality), there is a significant reduction in the total wild pig population, and the stable stage growth rate is almost cut in half (lambda = 1.34). When management is simulated in the yearling to adult class, there is still a decline in population, however this is less dramatic decline than when the piglet stage is managed. These findings show that management of the piglet stage can significantly influence the size of a wild pig population, and culling of the younger stages can be effective in reducing populations.

There are many important caveats to this model, and it is meant only to illustrate how dramatically management of piglet populations can affect the total population to managers. Survival probabilities need to be defined based on the location of the population, as there may be different survival rates in different areas. In this exercise, survival probabilities were primarily from research done in Texas. Further, survival of wild pigs is known to be tied to drought patterns and acorn mast (Barrett, 1978), and environmental factors should be taken into consideration when evaluating management strategies. This model does not take into account environmental stochasticity or carrying capacity. Finally, a more clear idea of what the actual population size is in the managed area would make the conclusions of this model more robust. Wild pigs are capable of producing up to three litters every two years, this model reflects a single time step of one year and one litter produced each year. A more useful model might take into account the higher fecundity of wild pigs if the population of interest exhibits this type of growth.

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# Appendix 4: Cost Benefit Analysis of Feral Pig Management on Tejon Ranch

## Introduction
Our project focuses on different management options for feral pig populations on the Tejon Ranch. Feral pigs are an invasive species that are causing wide spread destruction on the ranch. Our results indicate that Tejon could enjoy significant benefits by engaging in ranch-wide control efforts to limit the damage that feral pigs cause. This analysis is designed to be appropriate for either the Tejon Ranch Company or the Tejon Ranch Conservancy, and as such we simply refer to "Tejon Ranch" or the "Ranch" to refer to either organization.

## Goals of the Cost Benefit Analysis
Given the damage that feral pigs can cause, there are questions within the Conservancy about whether the value of the pigs as a hunting resource is worth the cost of the damage the pigs cause to the land. The Ranch has already made the decision that it needs to take steps to control the pigs throughout Tejon, but there are questions about what is the best way to for Tejon to move forward. Three primary options exist for the ranch: 1) pig-proof fencing 2) increased hunting pressure and 3) depredation of pigs, which involves live trapping. This CBA attempts to help Tejon understand the relative merits of the different management options available to them. We compare all three of the primary options on their own and then provide a land-price sensitivity analysis to inform what the best management option is for a given portion of land.

## Overall Assumptions for the CBA
- Each of these assumptions is a modifiable parameter within the model. Assumptions are based on relevant literature or conversations.
- All costs and benefits are direct costs and benefits. Because Tejon Ranch is making decisions on private lands, they internalize all costs and benefits associated with management decisions.
- There is no cost associated with securing a depredation permit, and the Ranch is able to secure a permit with CDFW for the entirety of Tejon.
- The Tejon Ranch Company is a private firm with numerous real assets that make it a very low risk firm. The Tejon Ranch Conservancy is a non-profit organization that is inherently low risk. As such a real discount rate of 4.5% is used to calculate present values for both organizations.
- All costs are calculated on a 20-year basis to reflect the anticipated longevity of any management options.
- Hunting is recognized as a reserved right for the Tejon Ranch Company and is treated as a baseline option. Both other control options are carried out in conjunction with the current commercial hunting program.
- Pig damage reduces the value of real estate or habitat by 50%
- 1 square acre is the unit of comparison for all control options.

## MANAGEMENT OPTIONS: COSTS

### *FENCING OPTION*:

This option entails strategically constructing fencing around areas that are being damaged by feral pigs. The goal of this option is to completely eliminate feral pig presence from fence exclosures. The design of the fence being considered has proven to be pig proof in other instances (Wilcox et al, 2004b). The design uses multiple strands of wire spaced lower to the ground to prevent pig passage. The estimated cost per foot is estimated to be $5.00 based on other nearby fences of similar design and recent estimates for the Ranch.

**Key assumptions:**

- Annual maintenance is 15% of the initial installation costs (Edwards, William, 2012).
- Fences are low enough that other game species hunted on the ranch (elk, deer, turkeys) are able to pass. Fence installation does not negatively affect other aspects of the Tejon's hunting program.
- Fencing off specific areas of the ranch will not significantly impact other wildlife corridors and should not lead to increased damage from pigs elsewhere on the ranch.
- The perimeter of a fenced acre is assumed to be square in shape.
- The rate of success for exclusion fencing is 90%.
- Pig fencing can improve the value of habtiat/real estate by no more than $5,000 per acre

### *DEPREDATION OPTION*

This option involves obtaining a large-scale depredation permit from CDFW for all of Tejon Ranch and culling pigs to reduce the overall population of pigs on the ranch to a desired level. This permit will give the ranch the autonomy to control the pig population as it sees fit. This program would not replace the current hunting program. Rather, it would supplement the existing hunting program and allow the removal of pigs by non-hunting means such as trapping. This can be especially important for removing pigs near residential areas where the use of firearms is not an option. Additionally, it can be effective at pressuring pig populations away from sensitive areas. The goal of such a strategy is to maintain the population at low enough levels in order to decrease the negative impacts of pigs on the entire ranch to include future residential areas, rangelands, and agricultural lands.

**Key Assumptions:**

- Depredation efforts are effective at improving habitat quality or land value for 1 $km^2$ from the point at which they are deployed.
- The rate of success for depredation is 20%.
- Depredation costs $600 per $km^2$ controlled.
- Maintenance fees associated with depredation are $300 per $km^2$ controlled.
- Depredation efforts are carried out for 3 months per year at any given location.
- Depredation efforts can improve the value of habtiat/real estate by no more than $2,000 per acre.

### HUNTING PRESSURE OPTION

Hunting is considered the baseline option and is therefore other options are carried out in conjunction with hunting. A key assumption is that there is no cost to the hunting program associated with other pig control efforts.

## RESULTS/DISCUSSION

Each of the three considered control efforts has the highest benefit to cost ratio depending on the potential to increase the land or habitat value. Until the potential to increase land or habitat value reaches $500 per acre, neither fencing nor depredation has a benefit to cost ratio above 1, meaning that hunting is the preferred control option. This would be the preferred control option for less valuable habitats or lands such as open grass lands.

When the potential to increase land or habitat value reaches $500-$3,100 per acre, depredation has the highest benefit to cost ratio. This would be the preferred control option for intermediate habitats or lands. These could potentially include woodlands that are not considered priority habitats or marginal agricultural lands.

When the potential to increase land or habitat value reaches above $3,100 per acre pig proof fencing becomes the preferred option. This option would be most suitable for high value agricultural lands, residential developments, or high value wildlife habitats and rare ecosystems.

Valuing ecological habitats can be quite challenging. While there is a growing body of literature to assist conservation oriented land managers in valuing their lands, quite a bit of local analysis still must be carried out. For example, freshwater wetland habitats have been valued between $43,675-351,591 per acre (King,1998) while proximity to oak woodlands in urban areas has shown to increase the value of homes by up to $10,000 per square foot (Standiford and Scott, 2008). In order to make this analysis most effective, land managers must consider the values of all different habitat types under their control and the amount by which engaging in pig damage control might improve the value.