EXOTIC PESTS and DISEASES

Biology and Economics for BIOSECURITY

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Historical Perspectives on Exotic Pests and Diseases in California

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Introduction

Pests and diseases have been destroying livestock and crops since the dawn of agriculture. The biblical accounts of plagues of locust and frogs, whether or not apocryphal, offer a hint that such problems existed in antiquity. This chapter picks up the story of pests and diseases at the beginning of modern agriculture in California in the mid-19th century. From the 1850s on, vast quantities of nursery stock and scores of new varieties of plants and animals were introduced into the state. In addition, the organization and density of agricultural production along with the supporting transportation, financial, and scientific infrastructures evolved rapidly. This created an ideal setting for all sorts of noxious plant pests and diseases to flourish.

California offers an unusually fertile ground for studying the impact of diseases and pests and for examining individual and collective control and eradication efforts. Given the remarkable array of crops grown in the state, California could host a large number of plant enemies. Moreover, the rapid introduction of new crops over the 19th century created what can be considered an enormous natural experiment. When the waves of farmers arrived following the Gold Rush, California was largely free of harmful insects and diseases. The growth of agriculture based on nonnative plants required importing nursery stock from other states and countries. Accompanying the new plants were pests and diseases that within a few decades were ravaging the state's crops. Their destructive power in some cases was so severe that they marked the end of the prosperity in leading producing areas. But perhaps the most interesting aspect of this history is the organized responses by the state's agricultural community to these new challenges. Just as the state was largely pristine territory before the surge in development, it was also largely devoid of the political, scientific, legal, and commercial infrastructures needed to combat the new threats. The spread of diseases and pests prompted collective action and research efforts that led to the eradication or at least the containment of the pest problems.

This chapter offers a brief historical account of a few key diseases and pests that had a significant impact on California horticulture in its formative years. This examination sheds light on the unusually successful, innovative, and productive research and outreach programs that emerged in the public and private sectors.[1] For crop after crop, the creative efforts of leading farmers, scientists, and government agencies overcame the "free rider" problem to literally save large-scale commercial agriculture. Table 5.1 provides a summary account of many of the significant institutional changes enacted to help protect agriculture. We do not attempt to measure the economic rates of return on these investments, but by any reasonable accounting they must have been enormous. The following accounts of the early campaigns against exotic pests and diseases will help illustrate some of the generic problems associated with pest control and eradication. Invariably, these campaigns were complicated because of the problems of imperfect information, of capital constraints, of externalities, and the need to lower the transaction costs associated with collective action.

Threats to the State's Vineyards

We start by examining three diseases that attacked what has become the state's leading crop—grapes. In the 19th century the vines of

Table 5.1 Partial list of U.S. and California efforts in plant protection (California efforts are in bold)

Year	Law/Institution	Purpose
1870	**First California plant pest control legislation**	**Various statues empowered counties to pay bounties for gophers and squirrels. Later, in 1883, the California Political Code gave county boards of supervisors power to destroy gophers, squirrels, other wild animals, noxious weeds, and insects injurious to fruit or fruit trees, or vines, or vegetable or plant life.**
1880	**Creation of the Board of State Viticultural Commissioners**	**Supplement the university's work in controlling grape pests and diseases with special emphasis on phylloxera. Remedy oriented rather than research oriented—the university was responsible for experimental and research work.**
1881	**California passes the first American law granting plant quarantine authority**	**The Act enlarges the duties and powers of the Board of Viticultural Commissioners and authorizes the appointment of a state viticultural health officer, who is empowered to restrain the importations into the state of vines or other material that might be diseased.**
1881	**Creation of County Boards of Horticultural Commissioners by County Boards of Supervisors**	**Eradicate specific scale bugs, codling moth and other insects. The county boards were empowered to inspect properties upon complaint and to require treatment of insect infestations. By 1882 county boards had been appointed in 21 counties.**
1882	**University of California offers its first course in economic entomology**	
1883	**Creation of the State Board of Horticultural Commissioners**	**Empowered with authority to issue regulations to prevent the spread of orchard pests and to appoint an "inspector of fruit pests" and "quarantine guardians" as enforcement officers.**
1885	**First explicit legislative authority to inspect incoming interstate and foreign shipments**	**Besides the local inspections, now the state inspector of fruit pests or quarantine guardian was authorized to inspect fruit packages, trees, etc., brought into the state from other states or from a foreign country.**
1886	**First county plant quarantine ordinance**	**Ventura county was the first county prohibiting transportation within the county of anything infected with scales, bugs, or other injurious insects. Other counties followed, and by 1912 at least 20 counties had enacted several ordinances against the entry of pests.**
1890	**Initiation of maritime inspection of cargoes of foreign vessels**	
1899	**California State Quarantine Law**	**The Act required the holding and inspection of incoming shipments of potential pest carriers and disposal of infestations to the satisfaction of a state quarantine officer or quarantine guardian of the district or county. Labeling of shipments was required, hosts of certain peach diseases were embargoed from infested areas, and importation of certain pest mammals was prohibited.**
1903	**The State Board of Horticulture is replaced by the State Commissioner of Horticulture**	**New body empowered to promulgate interstate and intrastate quarantines.**
1905 (March 3)	Insect Pest Act	Prohibited the importation and transportation, interstate, of live insects that are injurious to plants.
1905	**First California Quarantine Order**	**Issued because of the citrus whitefly of Florida.**

Table 5.1. (continued)

Year	Law/Institution	Purpose
1907	**Establishment of the Southern California Pathological Laboratory at Whittier**	**Do research studies on plant diseases and insect problems in Southern California.**
1910 (April 26)	**National Insecticide Act**	
1912 (August 12)	Federal Plant Quarantine Act	Prevent the importation of infested and diseased plants.
1912	Creation of the Federal Horticultural Board	Enforce the Plant Quarantine Act
1912	**Establishment of the Citrus Experiment station and Graduate School of Tropical Agriculture at Riverside**	**Superseded the Southern California Pathological Laboratory. Strong divisions in entomology and plant pathology.**
1912	**Work started at the University Farm at Davis**	**Carry out entomology and plant pathology research for the university.**
1912	**Development of the Agricultural Extension's County Farm Advisor Service**	
1915	Terminal inspection of plants in the U.S. post offices begins	
1919	Creation of the Western Plant Quarantine Board	
1919	**Creation of the State Department of Agriculture**	**Take over some of the duties of the State Commissioner of Horticulture.**
1919	Federal Quarantine Law No. 37	Regulate the movement of plants and plant products
1920	Federal Quarantine Law No. 43	Quarantine against the European corn borer.
1921	**Initiation of California border inspection of incoming motor traffic**	**Stations established on the roads coming from Nevada and Arizona. The original purpose was to prevent the introduction of alfalfa weevil. By 1963, 18 stations were in operation on all major highways entering from Oregon, Nevada and Arizona.**
1924	Quarantine on grapes from Spain	Prevent the introduction of Mediterranean fruit fly.
1925	Organization of the National Plant Quarantine Board	
1926	Federal Bulb Quarantine	
1928	Creation of the Plant Quarantine and Control Administration	Supersede the Federal Horticultural Board in its task of inspection of imports of nursery stock and other plants and prevention of plant pests.

Sources: Compiled from Weber 1930, pp. 1–90; Essig 1940, p. 40; Smith et al. 1946, pp. 239–315; Ryan et al. 1969, pp. 4–11.

California, and those in most of the world, were seriously threatened and at least once faced commercial extinction. The villains—powdery mildew, phylloxera, and Pierce's disease—still scourge the world's vineyards.

Powdery Mildew

California was largely spared the destructive impacts of powdery mildew (*Uncinula necator*) because the state's wine grape industry did not really take off until after reasonably effective control measures were developed in Europe. This represents a case in which California farmers were able to borrow a technology developed mostly in France and England. Powdery mildew (also known as oidium) was almost certainly indigenous to native vines found in the eastern states of the United States, and until the mid 19th century the disease was probably unknown in California and Europe. It was but one of a number of American diseases that doomed every effort to establish commercial wine grape production in the eastern and midwestern states. Over the ages native American vines evolved to coexist with this and other diseases.

But the vines of Europe (*Vitis vinifera*), which were to become the mainstay of the California grape and wine industries, had no prior exposure to this disease and lacked the defenses to ward off its effects (Pinney 1989).

The first serious attacks of powdery mildew outside of its native habitat occurred in England in 1845. According to E.C. Large (1940, p. 44):

> The disease appeared on the young shoots, tendrils and leaves, like a dusting of white and pulverulent meal; it spread rapidly on to the grapes themselves, withering the bunches when they were small and green, or causing the grapes to crack and expose their seeds when they were attacked later. The disease was accompanied by an unpleasant mouldy smell, and it ended in the total decay of the fruit.

By the late 1840s, oidium was ravaging vines across France, and by the early 1850s it was endemic throughout much of Europe, Asia Minor, and North Africa. The results were devastating, with losses often ranging between 50 and 90 percent of the crop. The area hardest hit was Madeira, where most of the population depended on the vines for their livelihood. The arrival of powdery mildew in Madeira in the 1850s destroyed the economy, leading to widespread starvation and mass emigration (Large 1940; Ordish 1987; and Pinney 1989).

As with many other new diseases, the causes and workings of powdery mildew remained unknown for several years while researchers and growers directed their efforts to learning the disease's pathology and to combating it. There were many false leads. In Italy, the appearance of the disease coincided with that of the first railroads. Peasants, putting these things together, blocked new construction and tore up miles of rails already laid to fight the disease (Pinney 1989). But others were both more scientific and successful in their approach. A.M. Grison and Pierre Ducharte in Versailles, J.H. Léveillé in Paris, the Reverend M.J. Berkeley and E. Tucker in England, and Giovanni Zanardini in Venice are all credited with making headway in combating the disease (Large 1940; Ordish 1987; and Barnhardt 1965).

By the early 1860s most French vines were regularly being sprayed with sulfur-based solutions, and by this time the knowledge of how to control powdery mildew was commonplace in California. The relatively late expansion of the grape acreage in California, the early use of sulfur, coupled with the relatively dry climate, probably account for the fact that the state's agricultural press recorded little damage from powdery mildew. This represents an example of scientific breakthroughs coming in time to ward off a potential crisis for the Golden State. Europe's experience with mildew was but a prelude to a far more devastating American invasion, and this time California's vineyards would not get off so easily.

Phylloxera

Phylloxera is a form of plant aphid that, like powdery mildew, was endemic in the eastern United States. The insect feeds on the vines' roots, weakening and eventually killing the plant. Phylloxera was first identified in Europe (where it was accidentally introduced with imported American rootstock) in 1863. It first appeared in California about a decade later.[2] By the mid-1870s the disease was ravaging the prime grape-growing areas of northern California. According to Vincent Carosso, more than 400,000 vines were dug up in Sonoma County alone between 1873 and 1879 to combat the pest. By 1880, phylloxera outbreaks had occurred in all of the state's wine grape-growing regions except Los Angeles (Carosso 1951; Pinney 1989). The future looked dire for California's vineyards.

As with the case of powdery mildew, advances in scientific knowledge eventually gave growers the upper hand in the battle against phylloxera, but the costs were staggering. Experiments conducted in both France and the United States during the 1870s and 1880s investigated literally hundreds of possible chemical, biological, and cultural cures. Most techniques, including applying ice, toad venom, and tobacco juice, proved ineffective. Four treatments appeared to offer some hope: submerging the vines under water for about two months, using insecticides (namely carbon disulfide and potassium thiocarbonate), planting in very sandy soils, and replanting with vines grafted onto resistant, native American rootstocks.[3] Only replanting on resistant rootstocks proved economically feasible, and even this course of action required an extraordinary investment. In the age before the biological revolution, often identified as beginning with the diffusion of hybrid corn in the 1930s, the vast majority of the vines of Europe and of California were systematically torn out, and the lands were replanted with European varieties grafted onto American rootstocks. This was a slow and painful process that resulted in severe hardship in the winemaking areas of the world. But the battle against phylloxera also represents an incredible biological feat; today most of the world's more than 15 million acres of vineyards are the product of the scientific advances and investments made in the 19th century. A few details of this story will offer a better sense of the achievement.

A number of early American growers had hit on the idea of grafting foreign vines on American rootstock. But grafting had no effect on black rot and the various mildews, which typically killed vinifera in the eastern and midwestern states well before the phylloxera had time to do its damage. This, along with the generally unfavorable climate in the eastern states, meant that grafting was not widely pursued. The idea of grafting onto American rootstocks to resist phylloxera reemerged in the 1860s and 1870s with the pioneering works of Charles V. Riley in Illinois and Missouri, Eugene Hilgard in California, and George Husmann in Missouri and California (Morton 1985; Ordish 1987; Carosso 1951; Pinney 1989).

Once the general principle of replanting on American rootstocks was established, much tedious work remained to be done and many detours and blind alleys had to be explored. The key problem was to discover which American varieties were in fact more resistant to phylloxera, which would graft well with European varieties, and which would flourish in a given region with its particular combinations of soil and climate.[4] In addition, grafting techniques had to be perfected. As with the initial attempts to introduce new grape varieties into myriad and largely unknown geoclimatic regions of California, the pursuit of information about the best grafting combinations required considerable trial and error as well as intensive scientific investigations.[5] In California, scientists working for the University of California, the Board of State Viticultural Commissioners, and the United States Department of Agriculture (USDA) all conducted experiments on a wide variety of vines and conditions. Similar efforts took place across Europe. As a result of the initiatives of Riley, Husmann, and others in Missouri, that state's nurseries became the leading producers of resistant rootstock for farmers across Europe. By 1880, "millions upon millions" of cuttings had already been shipped to France. Ordish estimates that France, Spain, and Italy together would have required about 35 billion cuttings to replant their vineyards (most of these would have been grown in European farms and nurseries after the first generations were supplied from America). To better appreciate the physical magnitude of this undertaking, 35 billion cuttings would have required roughly 12 million miles of cane wood—enough to circumnavigate the earth about 500 times (Pinney 1989; Carosso 1951; Ordish 1987).

In California, the very real threat that phylloxera would wipe out the state's vineyards played a major role in generating the political support for funding the institutions that would contribute immensely to the state's agricultural productivity. Most important was the work of the College of Agriculture of the University of California. In addition, as a direct response to the epidemic, the state founded the Board of State Viticultural Commissioners in 1880. After years of denial and foot dragging by grape growers, the new Board of State Viticultural Commissioners took aggressive action. It surveyed the infested areas; it made and published translations of the standard French treatises on reconstituting vineyards after phylloxera attack; and it tested the innumerable "remedies" that had been hopefully proposed since the outbreak of the disease in France (Pinney 1989). In 1880 the State Legislature also appropriated $3,000 for the University of California to expand its efforts in the fight against phylloxera. (As Pinney and others have noted, the relationship between the board and university researchers was seldom harmonious and often outright hostile.) Under Hilgard's enlightened leadership, the university spearheaded an impressive variety of research and outreach programs, including the dissemination of knowledge already gained in France. But in the 1880s the battle against phylloxera was still in its infancy. The general principles were understood, but detailed information on the best procedures and varieties for each microregion of the state had to be laboriously compiled, and the costly process of ripping out vines and transplanting onto the recommended rootstocks was only beginning. It was not until 1904 that the USDA initiated a systematic program of testing throughout the state. By 1915 about 250,000 acres of vines had been destroyed, but relatively little land had been replanted with resistant rootstock (Pinney 1989).

Pierce's Disease

In the late 1990s Pierce's disease emerged as a serious problem in California, causing a reported $40 million loss in recent years. Up and down the state nervous grape growers were demanding that something be done. In October 1999, the University of California announced the formation of a task force to mobilize the University's scientific, technical, and information outreach expertise to help the state's grape growers combat Pierce's disease. Amid much fanfare, California Governor Gray Davis proposed in March 2000 spending an additional $7 million per year to combat the disease.[6] A brief account of earlier outbreaks of Pierce's disease sheds light on the potentially devastating nature of this threat.

The historical accounts of the attacks of powdery mildew and phylloxera tell a story of how scientists created new information, technologies, and methods that allowed farmers to coexist, albeit at an enormous cost, with the diseases. The story of Pierce's disease is altogether different. It represents a frightening case study in which the early research efforts offered little or no support to the state's farmers. The disease systematically and totally destroyed the vineyards in what at the time was the heart of the state's wine industry, dramatically altering the fortunes of thousands of farmers and reshaping the agricultural history of California. Farmers in the infected areas had no recourse but to abandon their vineyards and search for other crops.

The story begins in the German colony of Anaheim, now in the shadow of Disneyland's majestic Matterhorn in the Santa Ana Valley. This agricultural community started with the organization of the Los Angeles Vineyard Society in 1857 with a capital stock of $100,000. After overcoming early organizational problems, the settlement began to flourish. The first vintage in 1860 yielded about 2,000 gallons. Production increased rapidly, from nearly 70,000 gallons in 1861 to over 600,000 gallons in 1868. By 1883 the valley was home to 50 wineries with about 10,000 acres of vines and a production of about 1,250,000 gallons of wine (along with a sizeable quantity of brandy and raisins; Pinney 1989). Prospects for the southern California wine industry looked bright. However, lady luck dealt the valley a cruel blow with the sudden emergence of an unknown affliction originally termed the Anaheim disease.

> The vineyard workers noticed a new disease among the Mission vines. The leaves looked scalded, in a pattern that moved in waves from the outer edge inwards; the fruit withered without ripening, or sometimes, it colored prematurely, then turned soft before withering. When a year had passed and the next season had begun, the vines were observed to be late in starting their new growth; when the shoots did appear, they grew slowly and irregularly; then the scalding of the leaves reappeared, the shoots began to die back, and the fruit withered. Without the support of healthy leaves, the root system, too, declined, and in no long time the vine was dead. No one knew what the disease might be, and so no one knew what to do. It seemed to have no relation to soils, or to methods of cultivation, and it was not evidently the work of insects (Pinney 1989).

Within a few years most of the vines had died. Prosperity had turned to economic ruin. The disease soon spread with varying severity to neighboring regions, contributing to the eventual demise of grape growing in what now comprises Los Angeles, Orange, Riverside, San Bernardino, and San Diego counties.

Even identifying the disease was a slow process, and after over 100 years farmers are still waiting for a cure. At first, several growers thought the vines might be succumbing to phylloxera, but careful investigation soon dispelled this notion. As more and more vines became infected, vineyardists asked the public authorities for expert opinion. Thus the Board of State Viticultural Commissioners and the University of California had to redirect scarce resources away from the phylloxera campaign to investigate the new Anaheim disease. In August 1886, Hilgard sent F.W. Morse, a chemist who had been working on phylloxera, on an inspection trip to the Santa Ana Valley. In his report, Morse described the conditions of the affected vines, the soil, the weather, and other conditions. However, he failed to detect any insects or microscopic organisms that could be held responsible for the mysterious disease. Thus, he erroneously concluded that the disease was probably due to particular weather patterns and that conditions probably would return to normal. Hilgard shared this optimistic prediction and so informed local farmers (Smith et al. 1946; Gardner and Hewitt 1974). Further studies by Morse and other agents of the Board of State Viticultural Commissioners were no more enlightening. The failure of state officials to identify the problem stimulated vineyardists to appeal to the federal government (Carosso 1951). Consequently, in 1887 the USDA dispatched one of its scientists, F.L. Scribner, to the infected area and enlisted the aid of Dr. Pierre Viala, an eminent French researcher who accompanied Scribner. After eight days examining the vines, they too were baffled by the affliction. Scribner concluded that a fungus did not cause it, and that the disease appeared in the roots. Viala suspected that a parasite might be at fault (Gardner and Hewitt 1974). When Anaheim disease appeared in the San Gabriel area in 1888, the Board of State Viticultural Commissioners, at the urging of one of its prominent members, J. De Barth Shorb, hired a "Microscopist and Botanist," Professor Ethelbert Dowlen. Shorb provided Dowlen with laboratory equipment and an experimental greenhouse on his estate. For several years Dowlen studied the problem, but without much success. He tentatively, but mistakenly, concluded that a still-unidentified fungus caused the disease.[7] Numerous other experts came and went, but the vines kept dying. Diagnosis ranged from plant sunstroke to root rot. Every manner of spray, dust, and pruning method was recommended and tried, but to no avail. These efforts were generally less outlandish than the reasoning that led Italian peasants to tear up the train tracks to fight powdery mildew, but they were no more effective.

It remained for another USDA scientist, Newton B. Pierce, to identify the disease. Pierce arrived at Santa Ana in May 1889. He imported 200 healthy vines from Missouri and planted some on the Hughes ranch in Santa Ana, where he located his experiment station. After several years of study that included a five-month stint in France investigating known vine diseases, Pierce was able to reject most popular theories (Smith et al. 1946). In 1891 he concluded that the disease was not anything already known, that it was probably caused by a microorganism, and that there was no known cure. By this time the wine industry had disappeared from the Santa Ana Valley. More generally, the spread of Pierce's disease in southern California was an important factor contributing to the shift in the center of the state's wine production. Between 1860 and 1890, Los Angeles County's share of production fell from 66 percent to 9 percent. In contrast, the share produced in the San Francisco region rose from 11 percent to 57 percent over these three decades (Pinney 1989).

Pierce's study closed the investigations of this vine disease for almost half a century. The hiatus was partly due to the difficulty of the task, but also because the malady mysteriously ceased being a serious problem. As a postscript, the identification of the bacteria responsible for the disease as well as a precise diagnosis of how it is transmitted has only been achieved in recent years. Research has shown that the disease is caused by a bacterium (*Xylella fastidiosa*) that is transmitted by a number of leafhoppers, including the smoke tree sharpshooter, the blue-green sharpshooter, and most importantly, the newly introduced glassy-winged sharpshooter. This latter insect is a far more effective vector than the other sharpshooters because it is larger, can fly further, and is more adept at boring into the vine's wood. When the sharpshooter feeds on a vine, it transmits bacteria that multiply and inhibit the plant's ability to use water and other nutrients. The disease is inevitably fatal. The incidence of the disease varies with the geographical characteristics of the surrounding countryside, because the sharpshooter thrives in wet sites with abundant weedy and bushy growth. It is now thought to exist in every county of the state. At present, short of attacking the vector (which most scientists think is at best a delaying action), there still is no effective method to control the disease. As with the battle against phylloxera, a successful strategy will probably depend on genetically altering the plant to better resist the disease.

Threats to the State's Tree Crops

The grape industry was by no means exceptional in its susceptibility to what at the time were exotic pests and diseases. Most fruit and nut crops faced similar onslaughts as new and often mysterious invaders took a terrible toll until methods could be developed to limit the damage. As noted earlier, when California gained statehood in 1850, the area was relatively free of pests and plant disease problems. Rampant and uncontrolled importation of biological materials changed all that, and by about 1870 a succession of invaders had attacked the state's crops, threatening the commercial survival of many horticultural commodities. In addition to grape phylloxera, some of the major pests that were introduced or became economically significant between 1870 and 1890 were San Jose scale, woolly apple aphid, codling moth, cottony cushion scale, red scale, pear slug, citrus mealybug, purple scale, corn earworm, and Hessian fly. Among the diseases to emerge in the 1880s and 1890s were "pear and apple scab, apricot shot hole, peach blight, and peach and prune rust" (Smith et al. 1946). Large orchards of single varieties added to the problem by creating an exceptionally receptive environment for the pests, and the state's nurseries further contributed to the difficulties by incubating diseases and spreading infected plants. Thus, within a few decades, California's farmers went from working in an almost pristine environment to facing an appalling list of enemies in an age when few effective methods had been developed anywhere for cost-efficient, large-scale pest control.

There was a general pattern to the appearance, spread, and control of new pests and diseases. At first the afflictions were not well understood, and the losses were often catastrophic. This led to the tearing out and burning of orchards, to quarantines, to the development of chemical controls, to a worldwide search for parasites to attack the new killers, and to the eventual developments of new cultural methods and improved varieties that were resistant to the pests or diseases. The University of California and government scientists spearheaded these various efforts and together made numerous stunning breakthroughs that fundamentally altered the course of agriculture. To illustrate, let us offer some historical detail on just two of the invaders—San Jose scale and cottony cushion scale.

San Jose Scale

San Jose scale (*Aspidiotus pernicious)* was first discovered in San Jose in the orchard of James Lick in the early 1870s. Lick, who is best known for the observatory he funded, was an avid collector of exotic plants. Most historical accounts suggest the scale hitched a ride on trees Lick imported from Asia. From his property it spread slowly to nearby farms and eventually to other parts of California. By the 1890s it had reached the East Coast and was active in all the main deciduous fruit-growing regions of the Pacific Coast. The fact that San Jose was a center for commercial nurseries undoubtedly hastened the scale's spread. At first, farmers were slow to respond to the new scale, in part because the pest took time to multiply and growers tended to attribute their losses to other causes because of its innocuous appearance. By 1880, farmers and scientists recognized San Jose scale as a grievous problem.[8]

The pest attacks all deciduous fruit trees, many ornamental and shade trees, and selected small fruits, especially currants (Marlatt 1902; Quaintance 1915). The scale infests all parts of the trees that are above ground, including the leaves and the fruit. If uncontrolled, San Jose scale could mean financial ruin to orchardists. On mature trees, the scale scars and shrivels the fruit, in many cases rendering it worthless. It can also stop growth and cause a systemic decrease in vigor, reducing the yield of the tree. Eventually, the tree dies prematurely, long after it has become economically unprofitable. If left untreated, most varieties of fruit trees infested at the nursery would not survive to bearing age (Quaintance 1915). The problem in the 1870s was that little was known about the scale and the technologies for dealing with it were not yet developed. Thus, as was the case when phylloxera began destroying the world's vineyards, the very future of the deciduous fruit industry seemed in doubt. Hundreds of thousands of trees were destroyed, property values in infected areas stagnated or fell, the development of new orchards temporarily stalled, and the agricultural press lamented the deterioration in fruit quality.

From the perspective of hindsight, the response to this and the other new pests of the period was truly remarkable. The university and USDA scientists were methodical in their search for biological and chemical controls. Coupled with these efforts, a new chemical industry with its own research, manufacturing, and sales forces came into being, and with it developed the modern agricultural spraying equipment industry. The relatively little attention that San Jose scale receives today is a testimony to the success of those efforts. But writing in 1902, one of America's foremost entomologists noted that "the fears aroused by this insect have led to more legislation by the several States and by various foreign countries than has been induced by all other insect pests together." (Marlatt 1902) At a time when California producers were beginning their struggle to gain access to international markets, more than a dozen countries, including Canada and many of the leading nations of western Europe, imposed restrictions or outright bans on the importation of American fruit because of the San Jose scale (Morilla, Olmstead, and Rhode 1999; Morilla, Olmstead and Rhode 2000; Marlatt 1902). In California, San Jose scale was one of the proximate causes underlying the creation of the State Board of Horticultural Commissioners in 1883 and the passage of the state's first horticultural pest control and quarantine law (Smith et al. 1946). These measures had an important impact on the development of the state's horticultural sector.

The fight to control the scale took two separate and at times competing tracks—biological and chemical. The discovery of biological controls was a high priority for the USDA. "The importance of discovering the origin of this scale arises from the now well-known fact that where an insect is native it is normally kept in check and prevented from assuming any very destructive features (or at least maintaining such conditions over a very long time) by natural enemies, either parasitic or predaceous insects of fungous or other diseases" (Marlatt 1902). The USDA's entomologists-turned-detectives focused their search on Asia, given the knowledge that James Lick had imported plants from Asia and that the disease was not known in Europe. By careful observation and deduction, they one by one eliminated Australia, New Zealand, the Hawaiian Islands, and Africa. Evidence appeared to point to Japan as the scale's home. But in 1901 and 1902 one of the USDA's entomologists, C.L. Marlatt, spent over a year exploring the farmlands and backcountry of Japan, China, and other Asian countries. His findings showed that the scale almost surely originated in China. He also found what he was looking for—an Asian ladybird beetle (*Chilocorus similis*) that feasted on the scale. Marlatt sent boxes of the beetles to his experimental orchard in Washington, D.C. Only about 30 survived the journey and only 2 of those made it through the first winter. With this breeding stock and fresh imports from Asia, the beetle population was increased and studied. Subsequently, roughly 20 other insect predators were identified and studied. Other researchers investigated controlling the scale with fungal diseases (Marlatt 1902; Quaintance 1915).

Although the attempts at biological control appeared promising, in the end they were not successful. Reflecting on these efforts, A.L. Quaintance (1915) of the USDA noted that "the combined influence of these several agencies [insects] is not sufficient to make up for the enormous reproductive capacity of this insect (San Jose scale)." A number of factors accounted for this setback. The primary agent, the Asiatic ladybird, often fell victim to native insects that preyed on its larvae. In addition, the practice of spraying to combat the scale killed potential predators and their food supplies.

The inability to perfect reliable biological controls encouraged farmers to rely on spraying as their primary defense against San Jose scale. The first insecticides used were mainly lye solutions to which several substances were added, such as soap, kerosene, tobacco, sulfur, carbolic acid, and crude petroleum. At first, the common practice was to spray the trees' foliage, but eventually farmers discovered that if they applied the chemicals during the dormant season they did not need to be as careful, and they could apply stronger doses without damaging their trees. About 1886 the lime-sulfur spray began replacing other washes, becoming a leading fungicide as well. The formulas were improved, and homemade concentrates started being replaced by standard commercialized preparations (Smith et al. 1946). As previously noted, the developments in the chemical industry and the spray equipment industry in the fight against San Jose scale would prove valuable in fighting other pests. In addition, many cultural methods learned in the fields, such as short pruning and shaping of trees to facilitate pest control, proved valuable in improving quality and reducing harvest cost (Marlatt 1902).

Cottony Cushion Scale

The history of the campaign against the cottony cushion scale (*Icerya purchasi*) represents one of the truly fascinating stories in the state's agricultural development. The cottony cushion scale sticks in bunches to the branches and leaves of citrus with devastating effects if uncontrolled. This scale was first observed in California in 1868 in a San Mateo County nursery on lemon trees recently imported from Australia. The scale first appeared in southern California's citrus groves during the industry's infancy in the early 1870s, and by the 1880s the damage was so extensive that the entire industry appeared doomed. Growers burned thousands of trees and helplessly watched their property values fall. The early attempts to control the scourge only increased anxiety (Stoll 1995).

Growers tried all manner of remedies, including alkalis, oil soaps, arsenic-based chemicals, and other substances that were being tested in the fight against San Jose scale, but the pest continued to multiply. Apparently, the cottony waxy covering of the scale protected it from the killing power of these liquid poisons. In desperation, both the USDA and the University of California pursued fumigating experiments for several decades. Fumigation involved the costly process of covering the trees with giant tents and pumping in various toxic gases. Experiments with carbon disulfide began in 1881. By the end of the decade hydrocyanic acid had emerged as the most promising treatment. Potassium cyanide, sodium cyanide, liquid hydrocyanic acid, and calcium cyanide all gained favor at one time or another in the pre-1940 era. Whereas these fumigation experiments were first aimed at cottony cushion scale, with the discovery of biological controls of that insect, the primary target eventually shifted to other pests (Smith et al. 1946).

Aware that cottony cushion scale existed, but did little damage in Australia, American scientists turned their attention to discovering why. They surmised that the scale was native to Australia and that natural predators limited its spread. Incredibly, bureaucratic and financial obstacles initially prevented the USDA from sending one of its scientists to Australia. Undaunted, Charles V. Riley, the chief of the USDA Division of Entomology, and Norman Colman, the California Commissioner of Agriculture, persuaded the U.S. State Department to allocate $2,000 to send USDA entomologist Albert Koebele to Australia, ostensibly as part of the delegation to the 1888 International Exposition in Melbourne. Koebele's true mission was to search for predators of the cottony cushion scale. He hit the jackpot on October 15, 1888, with the discovery of a ladybird beetle (vedalia or *Rodolia cardinalis*) feeding on the scale in a North Adelaide garden. Koebele sent a shipment of 28 ladybird beetles to another USDA entomologist, D.W. Coquillet, stationed in Los Angeles. Many more would follow. Coquillet experimented with the insects, and by the summer of 1889 the beetles were being widely distributed to growers. Within a year after general release, the voracious beetle had reduced cottony cushion scale to an insignificant troublemaker, thereby contributing to a threefold increase in orange shipments from Los Angeles County in a single year. According to one historian of this episode, the costs were measured in thousands and the benefits of the project were undetermined millions of dollars (Smith et al. 1946; Graebner 1982; Doutt 1958; Marlatt 1940).

This success encouraged Koebele to make another journey to Australia where he discovered three more valuable parasites helpful in combating the common mealybug and black scale. Other entomologists made repeated insect safaris to Australia, New Zealand, China, and Japan, as well as across Africa and Latin America. There were many failures, but by 1940 a number of new introductions were devouring black scale, yellow scale, red scale, the Mediterranean fig scale, the brown apricot scale, the citrophilus mealybug, the long-tailed mealybug, and the alfalfa weevil. In addition, scientific investigations led to improved ways of breeding various parasites so that they could be applied in large numbers during crucial periods (Smith et al. 1946). As with Koebele's initial successes, the rate of return on these biological ventures must have been astronomical.

Collective Action

These battles against plant pests and diseases represented classic cases of a geographically dispersed and economically diverse population trying to grapple with the problems of externalities and public goods in a democratic society.[9] Externalities are present when all the costs and benefits derived from an individual action are not completely borne or captured by the agent undertaking the action; in this case an agent's actions positively or negatively affect other economic actors. As a result, there is a gap between the costs and benefits to an individual agent (the private costs and benefits) and those to society as a whole (the social costs and benefits). The public goods problem arises from the lack of rivalry and excludability in consumption.[10] A successful eradication plan for a pest such as San Jose scale required protecting all the orchards in an infected area to prevent infestation. Because pest control displays characteristics of a public good and has positive externalities, leaving it to private individual initiative would likely encourage too little pest control, as reflected in the investments in research and in the application of prevention and eradication methods. In this situation, there is a case for public authorities to intervene by coordinating and leading individual efforts into a collective action cause.

Under these conditions, finance of eradication programs by voluntary contributions would allow individuals to benefit even though they do not contribute to the cost of the program and may not even cooperate with the pest control measures. This, in turn, creates a demand for collective action to employ the state (or some form of contractual authority) to coerce compliance in both the financing and operation of the control programs. Such actions necessarily limit individual freedom. In a democratic and market-oriented society, enacting such infringements on property rights can be a difficult and costly process. The fact that farmers not only acquiesced but also actively campaigned for such controls offers strong testimony as to the severity of the threats to their livelihood.

As discussed earlier, most of the diseases had recently been introduced from other parts of the world and were therefore unknown in California when the problems arose. To eradicate the disease from their private holdings, individual growers would have had to make enormous investments to develop basic and applied research programs and eradication methods. Given costly information and the small scope for expected private benefits, such investments were probably unprofitable for individual growers. Despite the substantial monetary losses from their individual economic point of view, it would have been more efficient to let the disease destroy their crops and maybe shift to less intensive production processes or to other crops. In fact, this was the course of action taken after the arrival of Pierce's disease, when vine growers of the Anaheim and San Gabriel Valley abandoned vines and planted citrus trees.

On the benefit side, the advantages of pest control to society as a whole are probably larger than those to individual farmers or even all farmers. Also important are the long-run or dynamic benefits derived from pest control. Practically all actions taken in this respect have had positive and significant spillovers to similar or related problems. For example, the fight against the pests and diseases of the last century led to basic and applied scientific discoveries that were crucial in improving the knowledge needed to combat other plant diseases. (In a number of cases the advances in agricultural sciences also had a direct bearing on improving human health.) The different eradication methods developed in the second half of the 1800s, such as the use of chemicals and insecticides, the breeding and grafting practices, the biological control by means of natural predators, etc., have been used extensively ever since. Similarly, much legislation concerning plant protection, such as quarantine and inspections laws, and a great part of the research and administrative institutions have their origins in the second half of the 1800s. Both the body of legislation and the state institutions detailed in Table 5.1 have effectively contributed to preventing the introduction and spread of diseases in California and elsewhere.

The efforts to combat injurious insects and diseases in California were built on earlier innovations in the understanding and control of disease. By the 1850s American agricultural leaders, including entomological and horticultural groups, were developing institutional structures that would provide the foundation for education, research, and collective action. In the 1840s, Solon Robinson and others organized the National Agricultural Society with the objective of directing the Smithsonian bequest to agricultural research. In the 1850s Marshall P. Wilder organized the U.S. Agricultural Society to lobby for the establishment of land grant colleges and the creation of a department of agriculture. The Morrill Act that granted land to the states for agricultural and industrial colleges was passed in 1862. By the early 1870s agricultural entomology courses were being offered in a number of colleges throughout the United States.

In California, important institutional structures began emerging shortly after statehood. Among the early institutions created were the State Agricultural Society and the California Academy of Sciences, organized in 1853. Both of these bodies promoted discussion and the exchange of information, but they were ill equipped to perform basic and applied research and outreach. In 1868 the University of California and the College of Agriculture were established to help fill this void. One of the college's early leaders, Eugene Hilgard, proved to be a man of enormous vision, talent, and energy. Trained in Germany as a biochemist and soil scientist, Hilgard established the policy of faculty having both research and extension responsibilities and took the lead in setting up experiment stations and a publication program aimed at communicating directly with farmers.[11] Much of the technical and research work on plant pathology that would lead to major breakthroughs in plant protection was undertaken at the university. Gradually, other state boards and institutions designed to deal with particular problems came into existence. One of the most important and active boards was the State Board of Viticultural Commissioners, created in 1880. This agency worked to provide information on phylloxera and supported research that tried to curb the ravages of Pierce's disease. But its legacy is tarnished, in part, by a long and often vitriolic squabble with Hilgard and other university scientists.

Quarantine and inspection laws provided another important tool in the arsenal to control pests and diseases. Here, California was a pioneer, enacting its first quarantine legislation in 1881. The legacy of these early efforts is with us today. Even the casual tourist entering the state by car encounters the state agricultural inspection stations designed to block pests and diseases that might hitchhike a ride into the state's fields. For most states it would be nearly impossible to stop the migration of pests and diseases from neighboring states. But California's long coast to the west and mountains and deserts to the north, east, and south offer natural barriers to migrating insects and diseases. With improvements in transportation and the increased mobility of people and commodities, the challenge of preventing new infestations has become even more daunting. But all future efforts, be they biological, chemical, or administrative in nature will be much easier to envision and implement because of the scientific and institutional foundations laid in the 19th and early 20th centuries.

Notes

[1]Our account is cursory in that it only touches on the problems of the horticultural sector and ignores the enormous problems that pests and diseases created for field and row crops and for livestock. Whereas California was a pacesetter in dealing with pests and diseases in the horticultural sector, the experiences with problems with other crops and livestock were important, but in many ways similar to what occurred in other states.

[2]Carosso (1951, p. 110) dates the arrival in Europe between 1858 and 1863. According to Pinney (1989, p. 343), "the disease had been discovered as early as 1873 in California", but this was when it was first positively identified by the Viticultural Club of Sonoma. Carosso maintained that the "disease was known to have existed in California before 1870 . . ." and vines on the Buena Vista estate probably had shown signs of infestation as early as 1860. See Carosso (1951, pp. 109-111); Butterfield (1938, p. 32).

[3]Ordish (1987, pp. 64-102) and most others use arcane 19th century terminology, labeling *carbon disulfide* (CS_2) as *carbon bisulfide* or *carbon bisulphide* and *potassium thiocarbonate* (K_2CS_3) as *sulphocarbonates of potassium*.

[4]"Resistance" is not a sure thing. When replanting onto apparently identical resistant rootstock, it is expected that about 20 percent of the plantings will be susceptible to phylloxera. In addition, over time the insects evolve to be able to overwhelm plants that previously had been resistant. Thus, the initial spread of phylloxera represented a watershed in the history of grape growing, and ever since it has been necessary to develop new resistant varieties to stay ahead of the insect.

[5]As an example, the first U.S. varieties shipped to France were labrusca and labrusca-riparia hybrids that had a low resistance to phylloxera. In California the initial recommendation that growers use *Vitis californica* for rootstock proved to be a mistake (Pinney 1989, pp. 345, 394; Carosso 1951, p. 125; Ordish, 1987, pp. 116–119).

[6]*The Washington Post*, March 27, 2000.

[7]Pinney 1989, p. 307; Gardner and Hewitt 1974, pp. 18-96. Dowlen reportedly had studied botany at the South Kensington School in London with Thomas Huxley and billed himself as a French expert on vine disease.

[8]Marlatt 1902, p. 156. It was in this year that it received its official name of *Pernicious*.

[9]For more on the economics of exotic pest and disease principles see Chapter 2.

[10]There is "rivalry" in the consumption of a good or service when the consumption by one agent pre-

vents others from enjoying it as well. This is not the case of a pest control program. Two farmers can simultaneously enjoy a plan's benefits without imposing additional costs on each other. "Excludability" exists when one can limit the access to a good. This is true of most goods sold in the marketplace. However, when a pest control program is under way, it may be hard to exclude any one farmer from benefiting from eradication efforts on nearby farms.

[11]Eugene Hilgard earned his Ph.D. in organic chemistry at the University of Heidelberg.

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