AN ANALYSIS OF THE POTENTIAL ECONOMIC IMPACT OF HUANGLONGBING ON THE CALIFORNIA CITRUS INDUSTRY

A Thesis

by

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Submitted to the Office of Graduate Studies and Research
of Texas A&M University-Commerce
In partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE
August 2012

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ABSTRACT

AN ANALYSIS OF THE POTENTIAL ECONOMIC IMPACT OF HUANGLONGBING ON THE CALIFORNIA CITRUS INDUSTRY

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The disease Huanglongbing (HLB), also known as Citrus Greening, was first discovered in the United States in 2005, in a Florida commercial citrus grove. HLB is a phloem limiting bacterium that reduces the life span of affected citrus orchards. Since its discovery in Florida in 2005, HLB has not only decreased citrus production, but has drastically increased production costs. With California contributing over 80% of the nation's fresh oranges, it is important to attempt to keep HLB from being introduced to the state. Quantifying the potential economic impact of HLB under different management approaches is essential in developing the most appropriate mitigation actions to take if HLB is discovered in California.

The total avoidable damages by keeping HLB out of California over a 20 year period is simulated under two different scenarios. If HLB is allowed to spread throughout the state without any attempts to limit its spread (i.e., a do-nothing or pessimistic scenario) for a period of

20 years, today’s total loss in production value, on average is estimated to be $2.7 billion. However, if California orange growers take aggressive actions attempting to limit the spread of HLB (i.e., an optimistic scenario), today’s total damages over the 20-year period considered are on average estimated to be $2.2 billion.

ACKNOWLEDGEMENTS

I would like to thank my advisor Dr. Lopez for his assistance throughout the entire process of completing this thesis. His directions and support encouraged me to keep at it and complete this study. Having someone to bounce ideas off of and gain insight to make my research stronger has been a rewarding experience. I would also like to thank Dr. Heitholt and Dr. Williams for being a part of my committee and for their feedback while completing this project. In addition, I would like to express my sincere appreciation to Dr. Williams. He will never fully understand how he has impacted my life by being instrumental in my pursuing an M.S. degree at Texas A&M University-Commerce.

Finally, it would not be right to go without expressing my deepest gratitude to Guy Eubank for his support and encouragement. Without his belief in me I would not have made the decision to relocate to Texas and complete my M.S. degree. Although he is no longer walking this earth and is not able to rejoice in this achievement with me, I know he would be proud.

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INTRODUCTION

Global citrus production is constantly being altered by various economic, biological and environmental forces. Weather, pests, and diseases are just a few natural and biological threats that affect the vitality of the world's citrus industry every year. As with any other commodity, new research and cultural practices are constantly evolving in an effort to combat the many environmental and ecological threats that commercial citrus production faces in the world's different dominant growing regions. To date, the greatest of these threats that citrus growers face is a bacterial disease known as huanglongbing (HLB). In the United States, the two main citrus growing regions are found in Florida and California, with California contributing over 80% of the nation's fresh oranges. Despite California's importance as the major fresh orange producing state, little attention has been given to quantify the economic impact HLB may have on the California citrus industry.

Huanglongbing

The disease huanglongbing, also known as citrus greening, was first discovered in the United States in 2005, in a Florida commercial citrus grove. Florida is not a stranger to invasive pests and diseases. Due to the high volume of agricultural imports arriving at local seaports and international airports, it is not surprising that HLB appeared. Two positive tests were confirmed by the United States Department of Agriculture (USDA) in Miami-Dade County in southern Florida on September 2nd (Animal and Plant Health Inspection Service, 2005). This news came as a heavy blow to the local citrus growers, who were already facing economic losses as a result of another disease, citrus canker, to which the industry had already lost nearly 30,000 acres of trees (Bronson, 2005). These detections set into motion changes in cultural practices, restrictions to domestic trade and spurred the allocation of millions of dollars to be set aside for related research funding.

HLB is a bacterium that affects all citrus cultivars. From the genus *Candidatus Liberibacter*, this phloem limiting, gram-negative bacterium, inhibits the flow of nutrients throughout the tree, causing a decrease in fruit production and ultimately the death of the tree (Bové, 2006; Citrus Research Board, 2011). Oftentimes, isolated limbs of the tree will exhibit symptoms before the entire canopy is completely infected. Limb dieback will occur, causing production to diminish until the tree dies. As the health of the tree declines, the fruit that is produced will be bitter, misshapen, remain green and small, in addition to an increase in early fruit abscission (USDA, 2011). Ultimately, the fruit produced is undesirable and unmarketable.

Within five to eight years of becoming infected, the tree will no longer be economically productive (National Research Council, 2010). In most cases where growers are attempting to limit the spread of HLB, the infected trees will be removed before they ever reach the point of being considered unproductive. There is no cure for this disease, so prevention is important. Symptoms may not present themselves in infected trees for up to two years. This potential for delayed symptom expression adds to the threat of this disease. If an infected tree is present in an orchard and is not known to harbor HLB, the ability of the bacteria to spread is enhanced.

HLB has been generally found to be transferred from tree to tree through three different means: the Asian citrus psyllid (ACP), the African citrus psyllid, and contaminated budwood propagation. Without any of these transmission methods present, the spread of HLB is limited. While the African citrus psyllid is considered a vector pest of HLB, it is not currently found in the United States and therefore is not a current concern in California. The Asian citrus psyllid, on the other hand, is found in the United States and has been a major concern in Florida and California.

In the United States, transmission through budwood propagation is the second most common method of infecting new trees. If tainted budwood is grafted onto a healthy rootstock, there is a significant chance that the rootstock will develop signs of HLB. In Florida where HLB is endemic, regulations have been put into place to minimize transfer of HLB through propagation. Nursery stock may only come from trees that test negative for the bacteria and are grown in screened nursery buildings.

The Asian citrus psyllid (*Diaphorina citri)*, which is the main vector of HLB transmission, was first detected in the United States in east Florida in 1998. The psyllid was found in a residential backyard on a known host plant, orange jasmine (*Murraya)*, in Palm-Beach County (CDFA, 2010). Although no definite answer will probably ever be known, it is thought that the psyllid arrived in Florida through nursery plant movement. Detections have also been made on host material that was harboring the psyllid in mail packages that arrived from areas of the world where ACP is known to be located. Since its introduction to the United States in 1998, ACP has been found in ten states, including Alabama, Arizona, California, Florida, Georgia, Hawaii, Louisiana, Mississippi, South Carolina, and Texas (Table 1.1). Detections of both ACP and HLB have occurred in the southern states. ACP and HLB detections and quarantine information for the United States is summarized in Table 1.1. Acting in the capacity of a vector of HLB, this species of psyllid has the potential to spread the disease anywhere the psyllid is detected.

At the time of initial introduction of ACP in Florida, HLB had not been detected. Therefore, no intensive mitigation measures were implemented to try to eradicate the ACP once the pest was discovered. Feeding on new foliar growth, the psyllid itself does not have much of an impact on fruit production. If infestations are high, the amount of sap that the psyllid extracts through feeding can harm the tree, but generally does not cause tree death. The honeydew that the psyllid excretes can make the environment more susceptible for sooty mold to develop, which has the potential to decrease fruit quality (APHIS, 2011).

Table 1.1. ACP and HLB Detections and Quarantine Information for the United States

State	ACP Detection	ACP Quarantine[b]	HLB Detection	HLB Quarantine
Alabama	2008[a]	Entire State		
Arizona	2009[c]	Portion of State		
California	2008[d]	Portion of State		
Florida	1998[a]	Entire State	2005[e]	Entire State[b]
Georgia	2008[h]	Entire State	2009[j]	Entire State[b]
Hawaii	2006[i]	Entire State		
Louisiana	2008[k]	Entire State	2008[k]	Portion of State[b]
Mississippi	2008[h]	Entire State		
South Carolina	2008[h]	Portion of State	2009[f]	Portion of State[b]
Texas	2001[e]	Entire State	2012[g]	Portion of State[g]

Sources: a. Majumdar et al. (2009), b. USDA (2011a), c. Blake (2009), d. Blake (2008), e. Grafton-Cardwell et al. (2006), f. Payne (2009), g. Texas Department of Agriculture (2012), h. Eggert (2008), i. Conant et al. (2009), j. Payne (2009a), k. Payne (2008).

HLB has been found in various regions throughout the top citrus producing countries and is known by many names throughout the world. Chinese for yellow dragon disease, HLB has no known cure or resistant citrus cultivar. A definite answer to where HLB originated is unknown, although it is thought to most likely have originated in China in the late 1800s (USDA, 2007). More than a century and a half later, HLB has been detected in the United States. As of February 2012, HLB has been found in Florida, Georgia, Louisiana, South Carolina, and Texas (Table 1.1).

Understanding how HLB changed the Florida citrus industry is important when analyzing how HLB may impact other states. Some of the programs that the USDA has implemented in Florida have been put into practice in California since the detection of ACP. Once regions of Florida and California were quarantined for ACP, all harvested citrus from those locations had to be commercially cleaned and packed before shipment out of the region is permitted (USDA, 2011c). Shipping regulations help limit the potential spread of green material that may be infected with HLB or contain the psyllid. The movement of nursery material and green waste is also restricted (USDA, 2011c).

Recommended grove management practices were also modified. By examining what helped decrease the spread of the disease in other countries, a three-step approach was suggested in Florida. Due to the lack of a cure for HLB, the only alternative is to attempt to control its spread. The first step consists of reducing the amount of available inoculum that is present to contribute to the spread of the disease. Removing infected trees reduces the amount of inoculum in the grove (National Research Council, 2010). The second step consists of intense ACP control measures to reduce the vector population (National Research Council, 2010). Since ACP is the main vector of the disease, keeping populations low is a key factor in limiting the spread of HLB. The final step is to replant the removed trees with healthy, uninfected trees grown in screened enclosures (National Research Council, 2010). Ensuring that disease-free trees replace diseased trees is necessary to keep the citrus industry's production from rapidly declining.

Consequently, nursery stock grown in screened enclosures became mandatory in 2008 (National Research Council, 2010).

World Citrus Production and Huanglongbing

For the past decade, the world's production value of citrus has been on the rise (Figure 1.1). According to the United Nations Conference on Trade and Development, citrus is the leader in terms of value in international fruit trade. Brazil, China, the United States, India, and Mexico accounted for 64.8% of the world's orange production in 2009 (FAOSTAT, 2009). São Paulo, Brazil and Florida account for 80% of the world's orange juice production, regions that both have HLB (Spreen, 2001). Brazil dominates both fresh and processed orange production worldwide as illustrated in Figure 1.2 (USDA, 2011d).

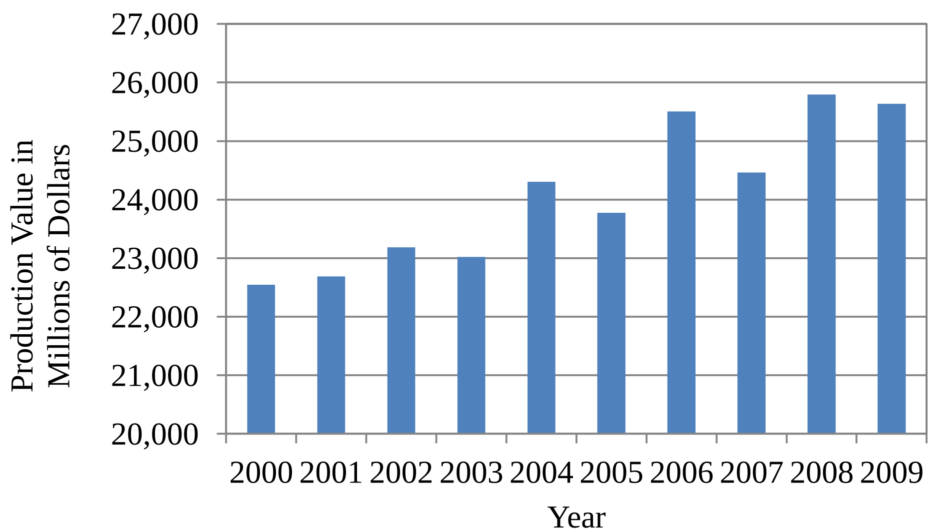

Figure 1.1. The World's Gross Production Value of Citrus, 2000-2009

Source: FAOSTAT (2011). Computed by Author.

Due to the fact that climates are different throughout the world, HLB vector pests are not always the same, although disease symptoms are similar. Two different strains of HLB are present in Brazil (National Research Council, 2010). HLB was discovered in Brazil in 2004, the year prior to its discovery in Florida. In 2010, it was estimated that at least 40 countries were faced with HLB, with roughly 100 million trees infected (National Research Council, 2010).

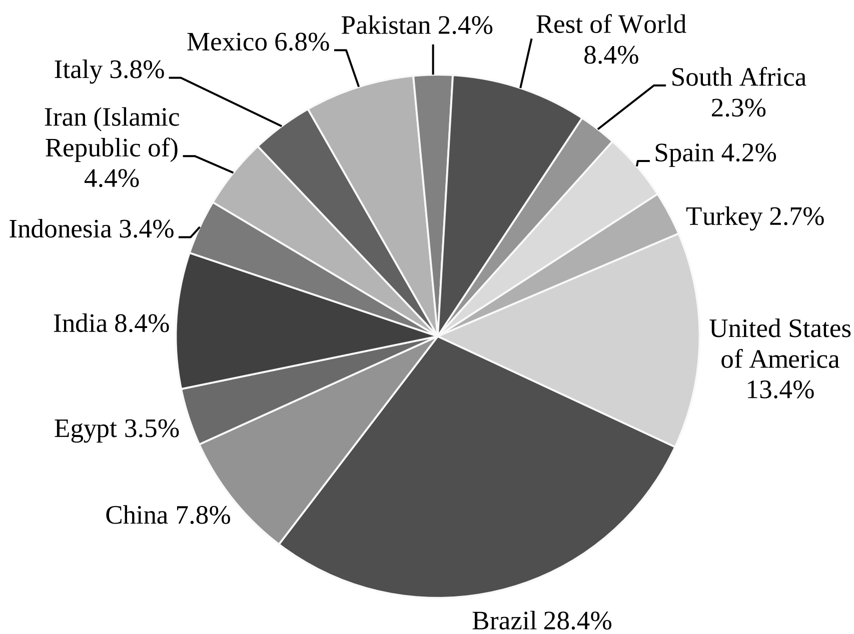

Figure 1.2. Worldwide Orange Production, 2009

Source: FAOSTAT (2009). Computed by Author.

U.S. Citrus Production

The top four citrus producing states in the U.S. are Florida (65%), California (31%), Texas (3%), and Arizona (1%) (USDA, 2011g). Species grown within these regions differ based on climate. Florida is known for citrus production that is primarily used for juice, accounting for 87% of the U.S. processed citrus production. California is the country’s top producer of fresh oranges and lemons, contributing 86.8% and 91.2% respectively in the 2009-2010 citrus growing season (USDA, 2011g). Texas contributed 18.4% of the nation's total grapefruit production during the 2009-2010 season (USDA, 2011g).

With its third place rank in U.S. citrus production, Texas's contribution to the citrus industry in 2006 and 2007 averaged $81.3 million per year (Niemeyer et al., 2007). In more recent years, while bearing acreage has held steady, production has been declining, reducing Texas's contribution to an average of $71.6 million per year (USDA, 2011g). Accounting for the remaining citrus production, Arizona is known for growing lemons. The 2010 U.S. citrus crop was valued at over $2.97 billion, roughly 15.5% of the total world production (USDA, 2011e; USDA, 2011g).

Florida's Citrus Industry

The first citrus tree was planted in Florida sometime in the mid 1500s (National Research Council, 2010). Since then, acreage has expanded into 577,000 acres throughout the state (Florida Citrus Mutual, 2007). Florida's citrus industry is now estimated to contribute nearly $9.3 billion to the state's agricultural sector, employing nearly 76,000 people every year (Florida Department of Citrus, 2011). Citrus accounted for over one-fifth of the state's total agricultural cash receipts in 2009 (Florida Department of Agriculture and Consumer Services, 2010).

According to the USDA, total citrus bearing acreage in Florida is at its lowest since the 1980s. The decline can be attributed to various reasons that have recently impacted the industry. In the years prior to the introduction of HLB, another bacterial disease, citrus canker became an increasing issue. Nearly 30,000 acres of trees died back or have been removed to stop the spread of citrus canker. Multiple hurricanes in the region have also helped contribute to the loss of trees. For the last several years the amount of bearing acreage has been decreasing by the thousands and production is decreasing at a significant rate (National Agricultural Statistics Service, 2010).

With the first detection of HLB in Florida in 2005, the U.S. citrus industry has seen firsthand the importance of controlling its spread. By mid 2011, the disease had stretched to 37 of Florida's 67 counties (Albritton, 2011). The last projected value that has been established as a direct cost of HLB to Florida's citrus industry is around $300 million annually (Wunderlich, 2010). In 2009, with more than 20% of the citrus crop infected with HLB, the production costs had increased more than 40% (Irey et al., 2008; Wunderlich, 2010).

The majority of the increased costs are derived from modified cultural practices. The changes were made as a result of recommendations by the United States Department of Agriculture (USDA) and the Florida Cooperative Extension Service, in an attempt to keep the spread of HLB from wiping out the entire Florida citrus industry. For instance, federal and domestic quarantines were put into place wherever HLB was detected in Florida until the whole state was ultimately quarantined. The quarantine set restrictions in movement of all fresh citrus products and plant material from leaving the federally-defined boundaries of the quarantine. These restrictions have since been revised, allowing for more open domestic trade (Schrack, 2011).

The importance of slowing the spread of HLB and ACP in the state of Florida was determined to be of economic importance. Attempts were made to decrease psyllid populations. Funding through the USDA, Animal and Plant Health Inspection Services (APHIS) and Plant Protection and Quarantine (PPQ) were set aside to help survey, monitor, treat and test for both ACP and HLB (Bronson, 2005). Millions of dollars have been contributed by various government agencies, commodity groups and private individuals to conduct research, in hopes of finding a solution to contain the affects of HLB.

California's Citrus Industry

The California citrus industry has been faced with numerous invasive pests and diseases that have had a negative impact on the industry in various ways. The USDA reports that about six new invasive pest species arrive in California every year, costing around $3 billion annually (Wunderlich, 2010). In 2008 the Asian citrus psyllid was detected in California, near the border of Mexico, where both HLB and ACP are known to occur.

California supplies the United States with over 80% of its fresh oranges and is the country's largest exporter of fresh citrus. While Florida has a larger amount of acreage dedicated to citrus than California, as illustrated in Figure 1.3, in 2009 California contributed 45% of the industry's nearly $2.9 billion value of production (USDA, 2011g). Employing around 26,000 people in the state (Wunderlich, 2010), the citrus industry is worth protecting from the spread of diseases.

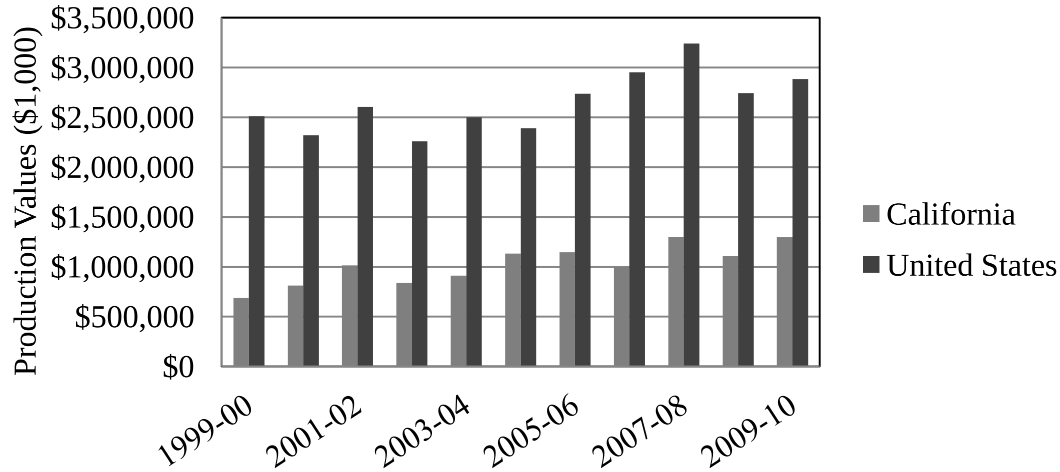

Figure 1.3. California Citrus and Total U.S. Value of Production

Source: USDA (2002; 2005; 2008a; 2011g). Computed by Author.

If HLB becomes endemic in California, the economic impact on the U.S. industry as a whole would be devastating. Citrus is grown in many counties throughout the state and many local economies are reliant upon continued production (Figure 1.4). Among the counties that produce over 50 acres of citrus are Butte, Fresno, Glenn, Imperial, Kern, Kings, Madera, Monterey, Placer, Riverside, San Bernardino, San Diego, San Luis Obispo, Santa Barbara, Stanislaus, Tulare, Ventura, and Yolo (see Figure 1.4). Not only would a loss in the production of citrus in California have the potential to increase domestic prices, but also a heavier dependence on imports may result. This could cause import prices to increase as a result of a lower quantity of domestically grown fruit being available. Citrus exports could also decrease. This is not only due to the fact that fruit availability could decrease, but a result of phytosanitary regulations that influence the ability to export citrus into other countries.

Figure 1.4. California Counties that Produce More than 50 Acres of Citrus

Source: USDA (2010). Created by Author.

While both Florida and California are the country's main citrus regions, the fruit is primarily grown for two different uses. Due to this difference in fruit utilization, it is expected that the potential economic losses from HLB would not be the same in California and Florida. The majority of the citrus in Florida is grown to process into juice, while the fruit in California is predominately grown for fresh consumption (see Figure 1.5). Even with Florida being the largest producer of citrus in the U.S., California's production value is the largest. This suggests that the presence of HLB in California will have the potential to impact the overall production value to a larger extent than what was seen in Florida.

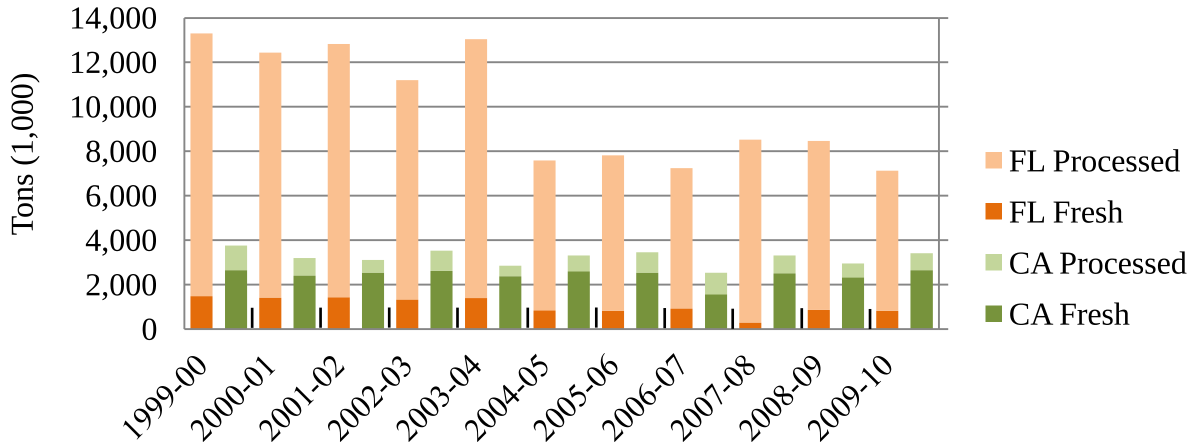

Figure 1.5. Florida and California Citrus Utilization

Source: USDA (2002; 2005; 2008a; 2011g). Computed by Author.

Oranges are produced in 15 of California's 58 counties (see Figure 1.6). The leading producer is Tulare County, with just over 50% of the state's total orange acreage. Tulare County is California's second largest county in terms of total agricultural production value. Kern and Fresno Counties have less than Tulare County in total orange acreage, with a combined 36% of the state's total (USDA, 2010). The remaining 13.5% of California's orange acreage is distributed in the remaining 12 counties highlighted in Figure 1.6 (USDA, 2010). While there is some production in a few of the northern counties (Glen, Butte, and Yolo), combined they represent less than one half of one percent of the state's orange acreage (USDA, 2010). As

California's 15th ranked commodity in terms of production value, orange production was found to be worth an estimated $720 million in 2010 (USDA, 2011f).

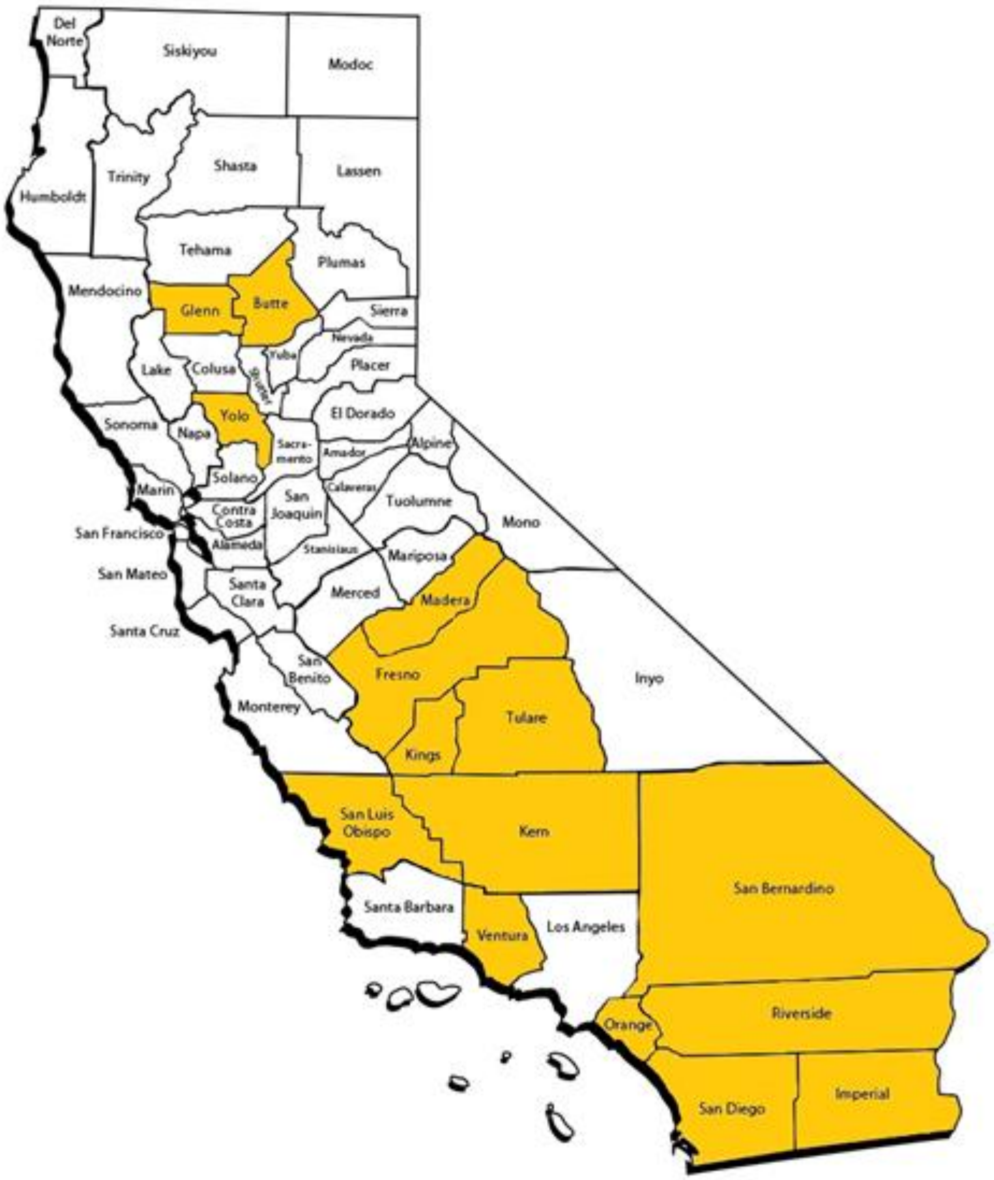

Figure 1.6. California Counties that Produce More than 50 Acres of Oranges

Source: USDA (2010). Created by Author.

Total orange bearing acreage in California has been decreasing since 1999, except for a slight increase in 2007 (see Figure 1.7). In 2011 the total orange bearing acreage was estimated at 180,000 acres. This is a decrease of 21,500 acres since the 1999 peak of orange bearing acreage over the 1992 to 2011 period (USDA, 1994; 1995; 1996; 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g). The decrease in acreage may possibly be attributed to an increase in the bearing acreage of tangerines. Since 1999, when bearing orange acreage started to decrease, tangerine bearing acreage has increased (see Figure 1.8), with an estimated 24,400 additional bearing acres seen by 2011 (USDA, 1994; 1995; 1996; 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g).

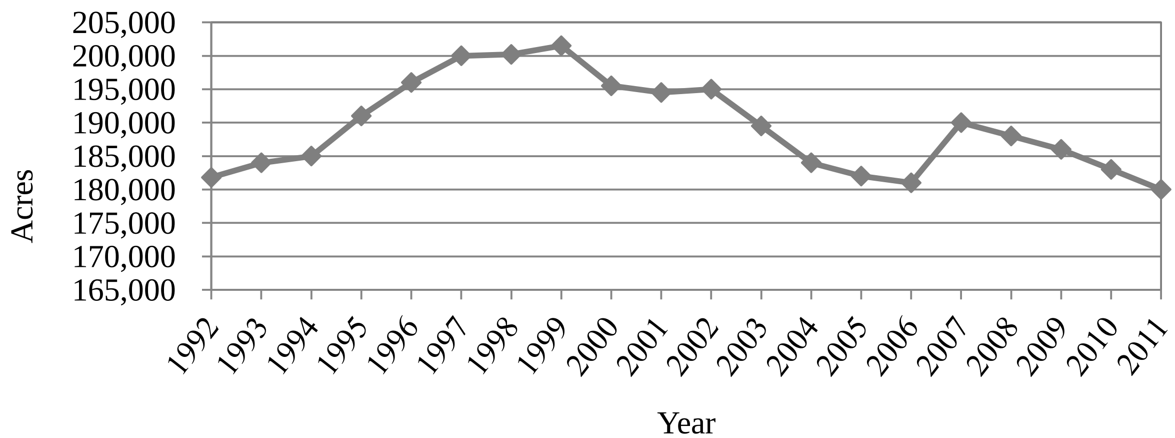

Figure 1.7. Total Bearing Orange Acreage in California, 1992-2011

Source: USDA (1994; 1995; 1996; 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g). Created by Author.

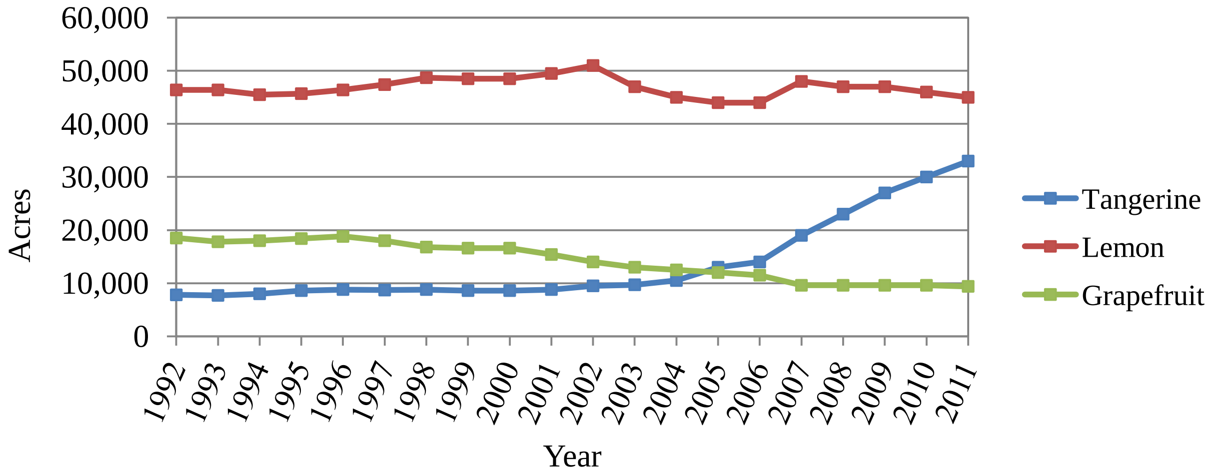

Figure 1.8. Total Bearing Tangerine, Lemon, and Grapefruit Acreage in California, 1992-2011

Source: USDA (1994; 1995; 1996; 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g). Created by Author.

Average orange production per acre has fluctuated between 242 and 354 seventy-five-pound cartons per acre from 2000 to 2011 (USDA, 2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g). As illustrated in Figure 1.9, an average yield of 308 seventy-five-pound cartons per acre over the last 20 years has been seen (USDA, 1994; 1995; 1996; 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g; Computed by Author). While the average yield per acre has fluctuated from year to year, the total orange yield for the state also changes, as the number of bearing acreage changes over time (see Figure 1.7). Figure 1.10 illustrates the estimated total number of 75-pound cartons produced in the entire state. Peak production in the last 20 years was seen in 1992 at 67,400 million cartons (USDA, 1994).

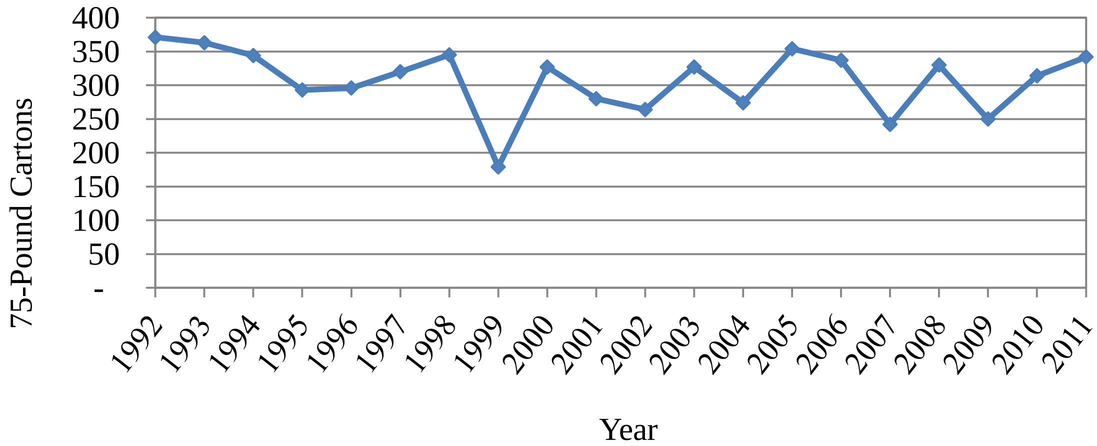

Figure 1.9. Average Orange Yield Per Acre in California, 1992-2011

Source: USDA (1994; 1995; 1996; 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g). Created by Author.

Oranges in California are predominantly grown for fresh consumption, although the fruit that does not meet fresh standards can be sold for processing. Towards the end of long orange producing seasons, orange groves are sometimes harvested strictly for processing. From 2000 to 2011 an average of 21.95% of the orange crop was sold as processed, as opposed to fresh (USDA, 2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g). The average amount of oranges sold for processing and as fresh fruit can be seen in Figure 1.10.

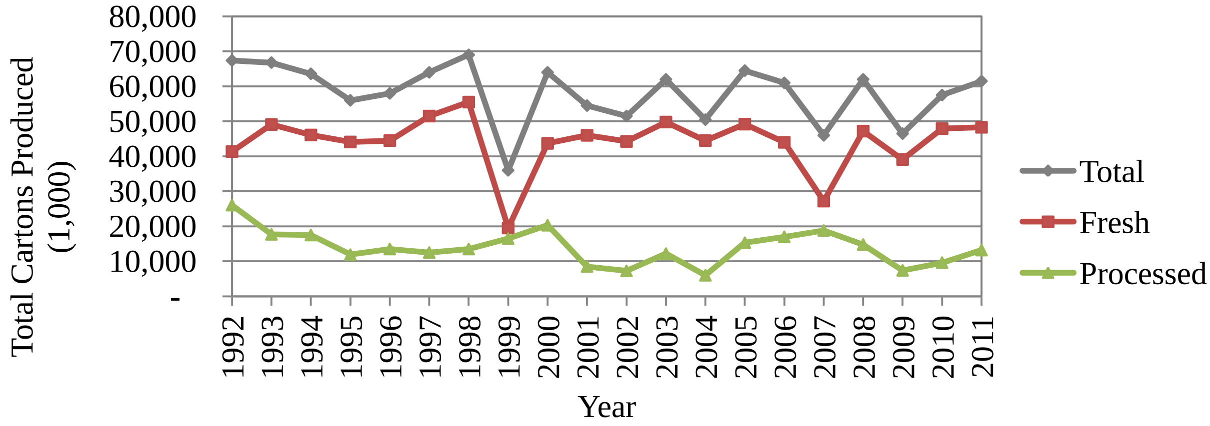

Figure 1.10. Total Orange Yields Produced in California in 75-Pound Cartons, 1992-2011

Source: USDA (1994; 1995; 1996; 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g). Created by Author.

Average citrus prices are published by the USDA in an annual citrus summary report, *Citrus Fruits Summary*. Until 2008, prices were broken down for the average fresh and average processed price. Since then, only total average price per carton has been reported. From 2001-2008 the average price received for fresh and processed oranges was $12.73 and $0.76 respectively (USDA, 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g; Computed by Author). The average annual prices from 1992 to 2011 are shown in Figures 1.11 and 1.12.

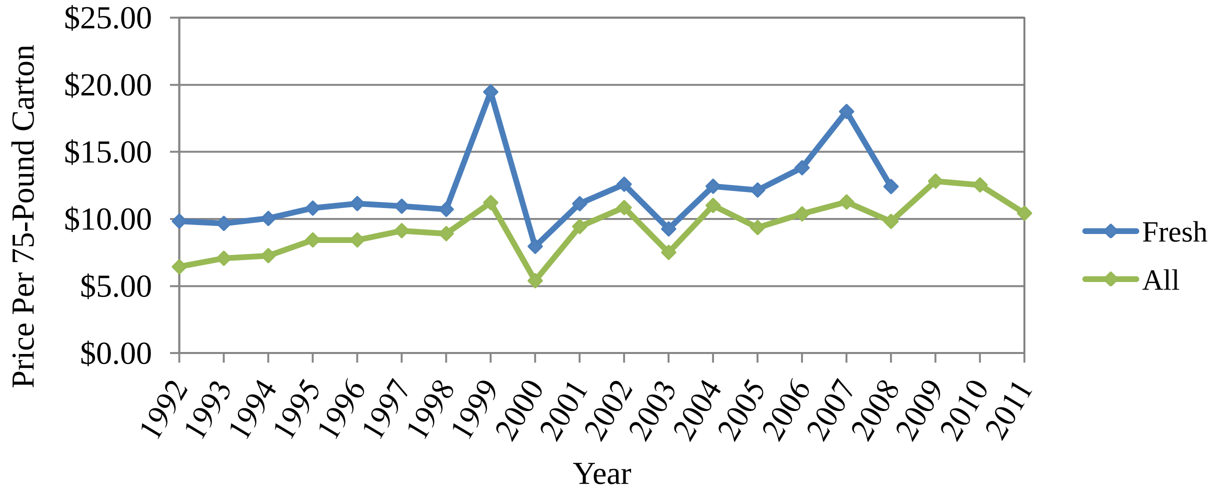

Figure 1.11. Average Annual Fresh and Total Orange Price in California, 1992-2011

Source: USDA (1994; 1995; 1996; 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g). Created by Author.

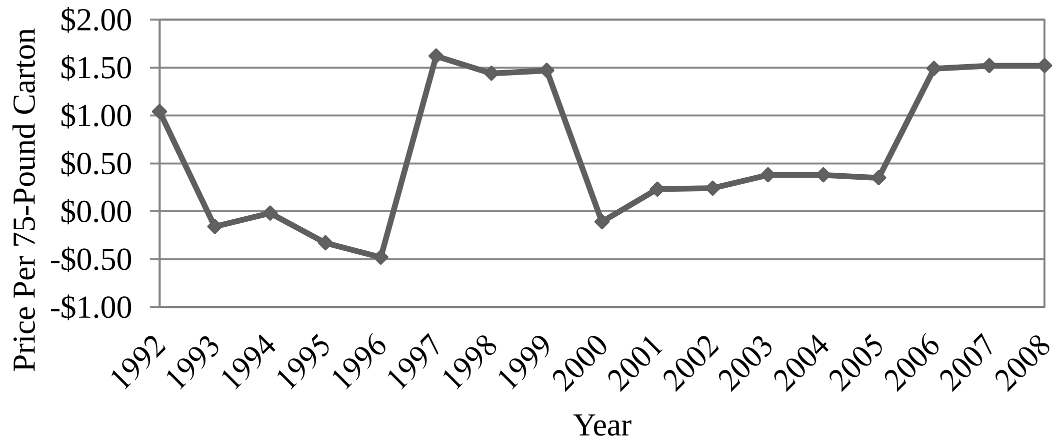

Figure 1.12. Average Annual Processed Orange Price in California, 1992-2011

Source: USDA (1994; 1995; 1996; 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g). Created by Author.

Objectives

The main objective of this research is to simulate the potential impact of HLB on the California citrus industry. Two management strategies will be presented, allowing for a comparison in the estimated total damage costs related to the presence of HLB. One strategy will estimate the costs associated with a do-nothing strategy, while the second strategy will include costs related to attempting to minimize the potential damage caused by HLB. Monte Carlo simulations are employed to estimate the total damage of HLB in California under both scenarios.

The total damage is the total cost that can be avoided by preventing HLB from becoming established in the state of California. The total damage cost can also be interpreted as an estimate of the benefits of keeping HLB out of California. The economic tradeoffs between the two strategies can be compared and may assist policy makers, cooperatives, unions, and/or farmers in determining how much money should be allocated to keeping ACP from becoming widespread and minimizing the chance of an HLB introduction.

Each approach has the different costs associated with producing under the presence of HLB. The do-nothing approach assesses the loss in production as HLB spreads through the state. This strategy is considered the worst case scenario of HLB spread in the state, and will be referred in this study as a pessimistic approach. Alternatively, the strategy that attempts to minimize the spread of HLB will be considered as an optimistic approach. The total damages included in this approach include both the loss in production, as well as the increase in overall production costs.

When attempting to estimate the potential economic impact of limiting the spread of HLB, the modified, required and/or recommended management practices for citrus production need to be taken into consideration. The management practices are in addition to analyzing the potential decreased yield loss as a result of young trees replacing older diseased trees. This type of yield loss is not present in the pessimistic approach as the yields in a do-nothing strategy will gradually decline over a period of time. The net present value of these total damage costs after 20 years from a hypothetical discovery of HLB is simulated and the results from each management approach are compared.

Specific Objectives

The specific objectives of this study are:

- To determine and estimate the costs involved with limiting the spread of HLB in California.
- To approximate the total loss in the value of orange production in California under a pessimistic and an optimistic scenario.
- To compare the estimated loss in production value of oranges over a projected 20 years to the value of production over the past 20 years.
- To compare the total damages under both a pessimistic and an optimistic scenario.

Determining and estimating the costs associated with implementing a management program designed to limit the spread of HLB are identified in Chapter 3. Estimations for the total damage incurred under the pessimistic and optimistic approach are reported in Chapter 4. Comparisons between the estimated loss in production value of oranges projected over a 20 year period is compared to the estimated production value of oranges over the past 20 years in Chapter 4. A comparison of the estimated total damages under the pessimistic and optimistic approach is made in Chapter 4.

Chapter 2

LITERATURE REVIEW

As the threat of huanglongbing (HLB) continues to disturb the citrus industry on a global level, related research is being conducted all over the world. Current research focuses on finding a resistant cultivar (USDA, 2012) and improving testing methods (Morgan et al., 2012). Until a cure or resistant cultivar is available, much debate over how to limit the spread of both the vector pest and the disease itself remains. As a result of the Asian citrus psyllid (ACP) being the primary vector of HLB worldwide, a great deal of research has been conducted related to this pest (Rogers et al., 2011; Sétamou et al., 2008).

Throughout this chapter, information related to HLB will be presented, including how the disease spreads, the rate of spread, and different management options used to mitigate the disease. Studies related to the vector pest and different ACP management practices will be presented. Information regarding other studies that have examined the potential economic impact of HLB in specific locations will be discussed. In general, there is limited information related to the potential economic impact of HLB, establishing the need for additional research. Despite HLB being the major threat to the citrus industry today, few studies have modeled the spread and economic impact of HLB, although no known studies have been conducted for California.

Asian Citrus Psyllid

Understanding the ecology of ACP allows for a better comprehension of how the disease spreads. ACP's lifespan can be several months. In most environments the psyllid will be active all year, although populations may be decreased during colder winter months. A female may lay up to 800 eggs during her lifetime (USDA, 2011c). Fresh new growth is required for her to lay eggs (Rogers et al., 2011). Once the eggs hatch, the nymphs feed on the new tender growths as they progress through their five different stages of instars. It is during this time that ACP are most susceptible to becoming carriers of HLB, through feeding on the new flush of infected tree. As an adult, the psyllid is able to hop and fly, allowing them to move from tree to tree by their own means, or with the assistance of heavy winds or human influence.

Keeping populations of ACP low is currently the most significant means of reducing further HLB incidences. This is because ACP is a vector of the disease. ACP population control generally leads to additional pesticide applications being made. Not only does this increase the cost for producers, but also puts more pollutants out in the environment and influences the population of other insects, both beneficial and detrimental. Attempts have been made to release beneficial insects to help reduce the psyllid numbers as an alternative method to increased insecticide use, although as reported by Brlansky et al. (2011) this method seemed to be ineffective.

Economic Impact of Invasive Species and Plant Pathogens

As sited by Pimentel et al. (2000), plant pathogens are responsible for $33 billion per year in U.S. crop losses. A few studies have attempted to analyze the economic impact of the spread of HLB. Niemeyer et al. (2007) conducted a study looking at the economic impact that HLB could have on the citrus industry, explicitly in Texas. Using the software program IMPLAN, a program that analyzes regional economics, Niemeyer et al. (2007) examined the potential impact at two and five years after a theoretical detection of HLB in Texas. Niemeyer et al. (2007) assumed a 20% reduction in production value after two years and a 60% reduction in production value in five years are plausible if no control measures were used. Setting a baseline of no widespread attempt at controlling or eradicating a pest or plant pathogen is common when attempting to examine their potential impact. The do-nothing approach also allows for a worse case estimate to be made.

Niemeyer et al. (2007) analyzed the impact that the declining citrus industry would have on other segments of the economy as jobs are lost and related business activity declines. After five years, a 60% reduction in production value is expected to decrease the number of jobs from 1,900 to 830 (a 56% loss) and would result in a $122 million loss. These were essentially IMPLAN's estimates of the citrus industries current production value under the nonexistent presence of HLB.

Salcedio et al. (2011) investigated the economic impact of HLB on Mexico's citrus production. Looking at what would happen to the economy as a whole, including primary fruit production and agricultural operations and businesses that are related to commercial citrus production, their study assessed three different levels of disease severity. After five years of high risk infection of HLB, it was determined that the total losses for the economy as a whole (including direct and indirect losses) would be estimated at $600 million U.S. dollars (Internal Revenue Service, 2012). Production losses would be different throughout the country depending on what type of citrus was grown in each region.

The economic impact of HLB in Florida has also been assessed. Hodges and Spreen (2012) estimated that a reduction of 23% in orange production during 2006 and 2010 was attributed to the presence of HLB. As a consequence, Florida's economy would suffer a $3.9 billion loss and total output, total value added and labor income would decrease. In addition, predicted total revenue received by growers exhibited a 12% decrease over the five-year span.

With HLB being a global threat to citrus worldwide, studies are conducted in various countries. Since the 1960s, Thailand has been plagued with HLB (Akarapisan et al., 2008). Citrus was once the leading fruit crop in Thailand. However, minimal private attempts at managing the disease have been taken, perhaps due to the fact that there are no government regulations regarding HLB in the country (Roistacher, 1996). HLB has had a large impact on Thailand's citrus production. With trees dying off before they become economically viable, Roistacher (1996) suggests that strict management guidelines be introduced. Some of these management practices include targeting pysllids with additional pesticide applications, removing ornamental citrus varieties from neighborhoods, and making it mandatory to certify nursery stock as disease free (Roistacher, 1996).

The ultimate goal Roistacher (1996) proposed was to be able to keep trees alive and producing for a minimum of 12 years. With the current cultural practices used in Thailand, trees need to last 8 years to have the possibility of returning a profit. Under the presence of HLB, at the end of 8 years, a farmer would be losing $1,482 per acre, whereas if the grove was able to survive to year 10, a profit of approximately $1,370 per acre could be realized. In Thailand, profit is not realized unless trees survive to reach 10 years, as it takes time to recover the costs of planting and caring for the tree until production revenue is high enough to cover costs. Trees infected with HLB produce at a lower rate than a healthy tree, therefore, it takes longer for a profit to be made. The key problem was that in some regions of the country, groves were only lasting 6 to 8 years.

Due to the fact of limited published data available for forecasting the impact of a variety of pests and diseases, stochastic bioeconomic models have been used to determine the total damage caused by pests in general (Waage et al., 2004). Cook and Matheson (2008) have been successful in modifying bioeconomic models for specific species. The total damage caused by a pest can be viewed as the benefit of keeping the pest from becoming widespread and eventually naturalized. Through estimating the marginal damage cost, the potential area affected by the invasive pest and the pest density, Cook and Matheson (2008) provided a conservative estimate for the total damages that may be avoided by limiting a pest's spread.

In this particular study, Cook and Matheson (2008) were analyzing the economic benefit of keeping pine pitch canker fungus out of Australia. Looking at how production practices would need to be altered if the fungus became widespread, a Monte Carlo model was used to account for the variability in possible cost that the presence of the fungus could have over time as it becomes widespread in the country. Utilizing both the direct costs and implication on revenue, Cook and Matheson (2008) were able to estimate the marginal damage cost of the pest at a given location. Using a 5% discount rate, over a period of 30 years, it was estimated that $6.2 million dollars could be saved by keeping pine pitch canker out of Australia. It was demonstrated that even with limited data available, it is still possible to provide an educated estimate of the benefit of remaining "free from" particular invasive species and plant pathogens.

Cook et al. (2007) also applied a similar stochastic bioeconomic model to estimate the benefit of keeping invasive species out of Australia. Cook et al. (2007) modeled the pollination service benefit of keeping the *Varroa destructor*, a parasitic bee mite, out of the country. One of the main challenges Cook et al. (2007) undertook is that the mite itself does not have a direct effect on production. They attempted to model the potential loss of pollination services as bees die off, which is essentially a secondary effect of the mite. Similar to Cook et al. (2007), this study attempts to analyze the secondary effect of ACP, or the spread of HLB. When using a discount rate of 8%, it was estimated that $27.5 million in damages could be avoided by keeping the *Varroa destructor* out of Australia over a 30 year period.

One main difference between Cook et al. (2007), the parasitic bee mite study, and Cook and Matheson (2008), the pine pitch canker fungus study, is the way that the marginal damage costs were estimated. Cook et al. (2007) accounted for the potential substitution rate of feral bees with bees from beekeepers, while Cook and Matheson (2008) did not need to account for any substitution rates. However, both studies take into account the additional costs incurred as cultural practices are modified and the decreased revenue as production levels decline.

The direct damage caused by HLB is the loss in yields, resulting from early fruit drop off and the removal of symptomatic trees. Although removed trees are replaceable, it takes several years for a young tree to produce fruit and they may not live long enough to be economically productive. Bassanezi and Bassanezi (2008) studied the impact of HLB on citrus yields in Brazil. They developed a model that could estimate the relative yield of citrus groves that were infected with HLB and were under no direct control for the disease. They assumed that if left untreated, the HLB growth rate could be estimated using a Gompertz function. In this function, the rate of HLB spread is slower at the beginning of the infection, then becomes rapid, and then slows down as full infection approaches. Accounting for the age of the trees and the severity of the disease, the results could be compared to the expected yield of a healthy block of trees. No actual values were provided, although the importance of applying disease control measures at the first onset of symptom expression was emphasized. Bassanezi and Bassanezi's (2008) research using the Gompertz function has been evaluated by research conducted by Gottwald et al. (2010).

Gottwald et al. (2010) compared and contrasted two different functional forms to appropriately model the potential spread of HLB. By analyzing several years of data tracking the spread of HLB in untreated orchards, they attempted to fit the data using a logistic and a Gompertz function. The Gompertz function was determined to best represent the incidence of HLB and was used to analyze HLB in Florida and assess the implications (yield loss) of its spread over a two year period. Using a stochastic model the study examined the spread of HLB through a 11,856 acre orchard in Florida. Trees that were identified as exhibiting symptoms of HLB were removed and not replanted, making the only source of introduction of the disease a single source of ACP at a single location. Trees were not replaced, therefore no new contaminated sources were introduced into the orchard. New young tree growth was therefore not present to attract ACP. Gottwald et al. (2010) concluded that not only did the disease spread out from the site of origination, but the continual availability of inoculum from the original source continued to encourage the spread. More importantly, as HLB spread it did so with healthy gaps of uninfected trees. This as well created a new source for the disease to begin spreading from.

Salifu et al. (2012) used the Bassanezi and Bassanezi (2008) model to analyze potential costs associated with HLB if no adjustments were made in current cultural practices in Florida. Accounting for the age of the trees and the rate of spread of HLB through a hypothetic citrus grove, reduced yields were determined by multiplying the relative yield of diseased trees by the average yield production of a healthy tree. Salifu et al. (2012) estimated how many years it will take for costs to exceed revenues as yields decline and HLB spreads at different rates through the citrus grove. Stated alternatively, Salifu et al. (2012) estimated the point in time that maintaining production no longer would cover production costs. It was estimated that for trees 10 years of age, revenues will exceed costs for up to 8 years after disease introduction. Bassanezi et al. (2011) examined potential yield loss contributed by the presence of HLB. Yields were reduced to some extent regardless of the severity of the disease. It was estimated that full grove infection would take place in a mature citrus grove after 20 years after the introduction of HLB.

Even though Salifu et al. (2012) explained three strategies to cope with the disease, the economic analysis was only presented for the "do-nothing" strategy. In addition, they assumed that when an incident occurs, the intensity with which it affects the citrus plant is 100%. Salifu et al. (2012) is among the few studies that have performed an economic analysis of HLB in the Florida citrus industry. Similar to the previously discussed studies, Salifu et al. (2012) will provide insight into the economic analysis of the California citrus industry.

In a study related to the spread of invasive plant species, Moody and Mack (1998) examine the concept of satellite sites. They recognize that spread does not just occur from one focus point. As new subset populations arise outside of the original site of introduction there is a new source that has the ability to spread, adding to the rate of growth throughout the environment. In fact, this pattern is illustrated by the way that ACP has been detected in California since 2008. Discontinuity between detections of the pest existed. The size and rate of each satellite site is independent of each other and is dependent upon the date of origin. This makes the date of detection to be highly important when attempting to discern where to allocate appropriate resource to eradicate or minimize an invasive pest. Cook et al. (2007) recognized this importance in their study of predicting the economic impact of an invasive species through studying the *Varroa destructor*.

Pest and Pathogen Dispersion

Determining the rate of spread of a pest is a challenge. Different environmental factors can be attributed to how rapidly and how successful an invasive species or pathogen can be, in addition to the number of original pest introduction sites. There are three known strains of HLB. *Candidatus* Liberibacter africanus (African), *Candidatus* Liberibacter asiaticus (Asian), and *Candidatus* Liberibacter americanus (American) have been found, all of which exhibit similar symptoms with different severity rates and are prevalent in different climates throughout the world. Elevation and temperature appear to be the determining factors of environmental conditions that determine which strain is able to thrive in various locations (Bové, 2006). *Candidatus* Liberibacter asiaticus is the strain that has been detected in North America (National Research Council, 2010). *Candidatus* Liberibacter africanus remains fairly isolated around Africa and parts of the Arabian Peninsula, while *Candidatus* Liberibacter americanus has only been found in parts of Brazil (National Research Council, 2010).

Since the Asian citrus psyllid is the main vector of HLB, various studies on how climate influences pest population in various regions of the globe have been conducted. Aurambout et al. (2009) developed a conceptual model to estimate the distribution of ACP under climate change. They concluded that temperature and climate are among the main contributing factors associated with pest dispersion throughout a region. Hong Liu and Tsai (2000) evaluated the intrinsic rate of growth of ACP under different temperatures and concluded that temperature plays a critical role in the psyllid population development.

Various studies have been conducted to determine the different means of transferring HLB. It has become common knowledge that without a psyllid vector pest, the disease is relatively limited to human spread through specific propagation techniques (Kobori et al., 2010;

USDA, 2007). Kobori et al. (2010) conducted two experiments to examine the diffusion rate of ACP. Their study suggests that the psyllid does not move very far without assistance. In the two experiments, the dispersal distance of the ACP was only 5 to 12 meters. Wind seems to play a role in natural movement of the pest. Provided that the bacterium is primarily spread through the vector pest, the Asian citrus psyllid, keeping the population of the vector pest low is currently the most significant means of reducing further contamination (Brlansky et al., 2011).

Gottwald et al. (1989) monitored the spread of HLB through three groves that were not under any disease treatment management program. The lifespan of the groves were drastically reduced. As a result of high infection levels, trees were removed before full grove infection was realized. The study estimated that this would take place between year seven and year thirteen, as results in individual groves varied. Importantly noted in this study was the observation that HLB spread in a cluster-like fashion.

In a field study conducted to track the spread of ACP, Boina et al. (2009) used the technique of immunomarking. Applying a protein spray to tree canopies, they were able to identify where psyllids were migrating from. Over a three-day period it was determined that ACP moved between both managed (treated for ACP) and unmanaged groves (no treatment for the past five years). In some instances, the psyllid moved over a 60 to 100 meter distance between groves. This greater potential for ACP to travel was supported by a study conducted by Hall and Hentz (2011), who observed that psyllids were found as far as 150 meters away from citrus trees. This distance suggests that the psyllid has the ability to disperse over greater distances than were exhibited in Gottwald et al.'s (1989) prior dispersal study. Dispersal patterns suggested that concentrating sprays on the border of citrus groves could potentially decrease the incidence of new ACP arrivals.

In order to implement an effective integrated pest management program (IPM), field managers need an accurate way to assess the extent of infestation of invasive species. Sétamou et al. (2008) conducted a study comprised of 34 commercial grapefruit and six sweet orange orchards in order to determine the required number of flush (new growth) that need to be sampled to estimate the dispersion pattern of ACP on citrus trees. During the time of year that citrus trees are at their peak of flushing, twenty flushes on ten randomly selected trees were examined from each of the 40 groves and data was gathered on the number of ACP in three stages of their life cycle.

Sétamou et al. (2008) implied that the cultivar influenced the density of the number of ACP at certain life cycle stages. The recommended sample size varies depending on the level of accuracy that is desired for each different life cycle stage. A decrease in ACP mean populations will require additional trees to be surveyed. Two to ten trees would need to be surveyed to be able to assess the amount of ACP that are present in a block of oranges or grapefruit. The amount of time it takes to conduct a survey was also taken into account. A time versus accuracy issue arises. Estimating the population of ACP is beneficial in assessing insecticide application requirements.

Other forms of transmitting HLB are being studied. Under controlled applications dodder has been used to successfully vector HLB (Zhou et al., 2007). Initial investigations on whether the disease may be transferred through contaminated seeds has been negative (Shikrollah et al., 2009). If rootstocks are contaminated, top working trees is not a viable choice when attempting to remove the disease from a grove, as Shikrollah et al. (2009) has determined that new graftings on such rootstalk will become infected.

Management Practices

Management practices play an important role in the dispersion of HLB over time. Aggressive management practices may allow contaminated groves to stay economically viable. Morris and Muraro (2008) evaluated the profitability of utilizing three different management practices that are available to growers. These three options are implementing no management practices, resetting removed diseased trees, and increasing the tree density in orchards. Of these three practices, the most profitable option was determined to be removing infected trees and replanting. Morris and Muraro (2008) concluded that although the tree removal option is deemed to be best, the surrounding environment plays a large factor. If neighboring grove managers are not actively pursuing keeping HLB at minimal levels, there may be no viable choice to keep an orchard producing at rates that are economically sustainable.

Belasque et al. (2010) evaluated government recommended practices in Brazil through observing 18 farms infected with HLB. These recommendations are similar to those established in Florida since the 2005 discovery of HLB, including scouting for and removing diseased trees and replanting with healthy trees from screened nurseries. They found there to be a large range in the costs associated with implementing these management practices. This same trend is expected to be present in the U.S.

Costs associated with continual scouting of citrus groves year round, tree removal, and increased chemical control of ACP populations all were attributed to the increased costs of operating under HLB endemics. The difference in scouting costs came up to a range of $5.26 per acre each year, while depending on the type and number of treatments, up to more than $400 per acre each year in additional insecticide applications. Of the 18 farms in the study, the most successful ones were larger farms that started aggressive treatment from the start. Delaying the adjustment in management practices played a large role in the sustainability of the farm.

Irey et al. (2008) evaluated the direct and indirect costs associated with attempting to manage groves that are harboring HLB in Florida. While only analyzing at the costs and not any additional losses due to decreased fruit production, they concluded that an aggressive HLB management program has the potential to increase production costs by 40%. Some of the increase in production costs noted in this study included scouting for diseased trees (around $25 per acre, per inspection), increased insecticide applications ($410 per acre), diseased tree removal ($3-7 per tree), and the cost of replanting with disease free trees (up to $9 per tree). Determining the level of indirect costs associated with producing under post-HLB conditions were harder to quantify, but were explained to be linked to administrative costs and the detrimental impact of additional pesticide applications related to the new integrated pest management strategies.

HLB management practices in Florida have been recommended by the Florida Cooperative Extension Service (Brlansky et al., 2012). Scouting for HLB a minimum of four times per year, identification of symptomatic trees followed by immediate removal, replanting with certified nursery stock and applying measures to minimize the ACP population are included in these management recommendations. Unlike any of the studies already mentioned regarding post HLB management practices, Branksky et al. (2012) recommends applying a foliar insecticide to diseased trees prior to removal to minimize the dispersal of infected ACP from the tree upon removal. It is reasonable to assume that since these recommendations mimic what has reportedly been successful in other areas of the world, that the same recommendations would be implemented in California if HLB is detected.

Salifu et al. (2012) undertook a study that addressed three different strategies that have been seen in Florida. The first strategy consists of no changes in cultural practices. HLB is free to migrate through the grove at an unobstructed rate. Strategy two follows the recommendations of Brlansky et al. (2012) through the Florida Cooperative Extension Service. The final strategy entails applying foliar micro and macro sprays to combat the damage caused by HLB in the tree. This final strategy is costly ($200-600 per acre) and does not remove infectious sources from the grove (Salifu et al., 2012).

Stover et al. (2008) provided predictions of what could become of the Florida citrus industry post HLB. They recognize that the current cultural practices will need to be modified with HLB being present. Applying a 3%, 10%, and 30% loss rate per year for citrus trees in endemic regions, they estimated the survival rates of groves with initially different tree per acre rates after 12 years. They suggest that an Advanced Production System be applied, in addition to an Open Hydroponic System. This simplifies into planting more trees per acre than what is currently a conventional method. This helps ensure the longevity of the orchard as HLB infected trees are removed. It is important that the orchard remains viable long enough to cover the costs associated with establishment. Irrigation and nutritional methods would be modified to switch from the goal of obtaining a large canopy size to earlier tree maturity. This would allow for fruit to be harvested earlier.

Higher density plantings have been introduced in the past, although growers were unwilling to adopt this approach. Concerns included equipment not being suited for tighter trees. After examining China and Africa where this type of growing practice is starting to be used to rejuvenate the local citrus industries, Stover et al. (2008) found there to be some validation for attempting to modify it to suit Florida's environment. Removal of infected trees is only a temporary solution and will not promote economic sustainability (Stover, 2008).

Due to the importance of citrus grove management in keeping incidences of HLB from spreading through entire citrus producing regions, the Institute of Food and Agricultural Sciences, University of Florida Citrus Research and Education Center developed a guide to help direct farmers to keep an economically viable crop in the presence of the disease. Some of the goals that were recommended included keeping the percentage of infected trees at around 2% through scouting and symptomatic tree removal. Spann et al. (2010) recognize that this method isn't always effective, as they estimated that identifying infected trees through scouting was only 50-60% effective. The time it takes for symptom expression is long and allows for unidentifiably infected trees to remain in the grove supplying more sources of the inoculum.

Determining which practice is best suited for each individual grove depends on many factors. The current situation of the specific grove and that of the surrounding area must first be assessed. Current methods of control must be evaluated to see if they are being employed rigorously and consistently. Spann et al. (2010) concluded that a reasonable choice will depend on the current level of infection and the grower's long term plans. A summary of the more commonly used options is shown in Table 2.1.

Table 2.1. Summary of Available Options to Manage HLB

Options	Description
1	Do not make any changes to the current management practices.
2	Attempt to control ACP populations.
3	Attempt to control ACP populations and remove diseased trees.
4	Foliar nutrition program.
5	Combine option 4 with option 2 or 3.

Of the available options for living with HLB, the usual goal is to attempt to limit the spread of the disease. The common practice is to identify symptomatic trees, remove them, and attempt to control ACP populations. The other most commonly selected option is to do nothing. In some cases growers abandon their groves (USDA, 2010b). This would be the ultimate do-nothing strategy. Each option has its own financial implications involved, either drastically decreased yields, or higher production costs due to modified cultural practices.

Chapter 3

METHODS AND PROCEDURES

In order to have a better understanding of the economic impact of HLB in California, two different scenarios will be explored. These scenarios will consider the potential economic impact of reduced yields and increased costs associated with HLB management, or lack thereof. In the first scenario, HLB is introduced into California and no changes are made in an attempt to limit the spread of the disease. HLB is projected to spread rapidly throughout the state under this scenario. This will be referred to as the pessimistic approach and it tracks the revenue repercussions as yields decline over time. In the second scenario, HLB is introduced into California and there is a statewide attempt to minimize its spread. Like the pessimistic approach, this optimistic approach will track the reduced revenue from production as yields decline, in addition to the costs associated with attempting to minimize the spread of HLB.

ACP is currently found only in southern regions of California. It is possible that ACP may be eradicated from the state. While this is possible, it is not probable, as reintroduction is very likely to happen since ACP is found in Mexico and Arizona, which border California. In order to analyze how HLB may impact the orange production in California, this study assumes that ACP spreads through the state and becomes a naturalized species. ACP naturalization means that once HLB is introduced, it has the potential to spread through the entire state. This assumption will be the same for both the pessimistic approach and the optimistic approach.

The Pessimistic Approach

If farmers were to make no changes in cultural practices after an introduction of HLB, the disease would ultimately reduce yields as it spreads through the state. It would be difficult to keep production levels high enough to be economically productive. Attempting to replant would be difficult, as new trees are extremely susceptible to infection and would probably die prior to producing any fruit. Therefore, this approach assumes no replanting attempts. This can be characterized as a do-nothing or pessimistic approach.

Due to the importance of the entire citrus industry in California, a do-nothing strategy would most likely be rejected by the majority of growers, although some may adopt this approach. However, assessing the loss in production value under a worst case scenario allows for comparisons to be made with a do-something strategy or optimistic approach. This comparison provides an estimate of the additional damage that could be avoided by adopting modified cultural practices. This comparison is useful for the California's citrus boards, citrus growers, and/or governmental institutions to promote adopting a strategy to minimize the spread of HLB. In addition, growers will be able to evaluate the long-term importance of removing diseased trees, even when they are still economically productive.

HLB Severity in Individual Trees

Understanding how quickly HLB can move through a tree and begin to render it unproductive can help illustrate how important it is to attempt to control the spread of the disease. Following the model proposed by Bassanezi and Bassanezi (2008), this study estimates how initial HLB disease severity can change how fast HLB may progress through a tree (Figure 3.1). The age of the tree is a determining factor of the speed at which HLB progresses through the canopy. Younger trees are fully infected at a quicker rate. This is due to the fact that they have more new growth to attract ACP, which in turn feed on the trees, transmitting HLB if the ACP are carriers. This creates an environment that is ideal for multiple individual bacterial transmissions to occur, leaving HLB to spread from many different locations in the canopy. The amount of canopy area for the disease to spread through is also much smaller in young trees than in a mature tree and reaches 100% of the infection capacity at a much quicker rate than in a mature tree.

Following Bassanezi and Bassanezi (2008), Figure 3.1 estimates the level of disease severity in an individual tree over time. The severity, or incidence level, is assumed to progress until it reaches 100%. A two-year-old tree is estimated to be completely infected in less than two years, whereas a 10-year-old tree may take up to 10 years. Throughout the time between initial infection and complete infection the tree may remain productive. An infected tree's production will decline as it reaches 100% infection. From there, it may still continue to produce fruit until the tree dies, although fruit quality will most likely be degraded.

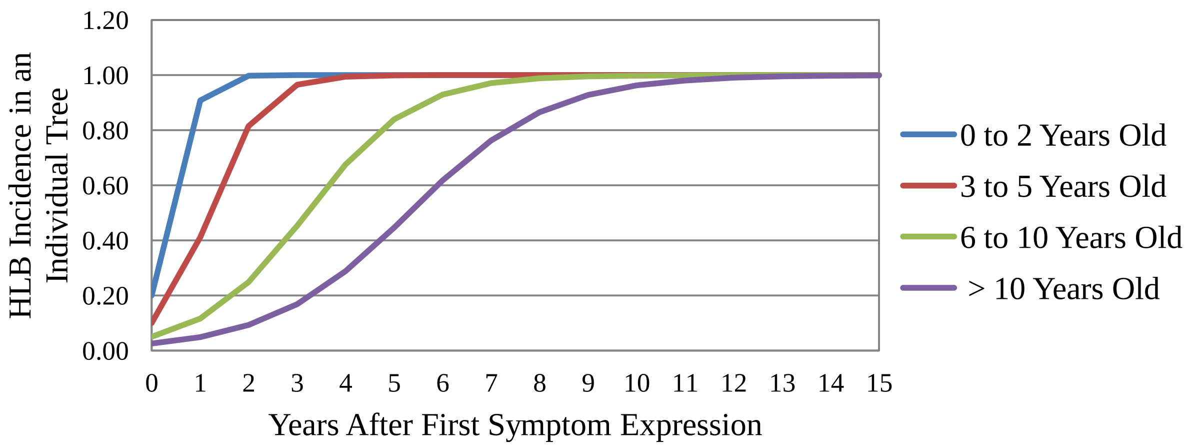

Figure 3.1. HLB Severity in an Individual Tree

Source: Bassanezi and Bassanezi (2008). Computed by Author.

The proportion of HLB severity in an individual tree (s) is approximated by

(3.1) $$s_t = \frac{1}{1+\left(\left(\frac{1}{s_o}-1\right)e^{-rt}\right)},$$

where s_o is the initial proportion of symptom expression and r is the rate at which HLB moves through the tree in year t (Bassanezi and Bassanezi, 2008). Table 3.1 outlines the various parameters that are used to calculate s for different tree age groups. These values are consistent with Bassanezi and Bassanezi's (2008) reported values. With canopy size varying between these different age groups of trees, the older the tree, the lower the initial proportion of symptom expression. The older the tree, the less new growth for infected ACP to feed on. This establishes that the older the tree, the number of infections is usually lower, causing the slower rate of spread throughout the entire tree. HLB is estimated to progress through young trees (r = 3.68) at such fast rates that the tree may never become productive. The increased rate of spread in young trees makes replanting nearly impossible when no control measures are in place. This is due to the fact that the new trees will most likely die prior to producing any fruit, as they are highly likely to become infected shortly after planting.

Table 3.1. Parameters Related to the Age of Trees and HLB Severity

Parameter	Definition	Tree Age			
		0 to 2	3 to 5	6 to 10	> 10
s_o	Proportion of symptom expression in individual trees	0.2	0.1	0.05	0.025
r	Annual rate of progress in an individual infected tree	3.68	1.84	0.92	0.69
R	Annual rate of incidence progress through the state	1.3	0.65	0.325	0.244

Source: Bassanezi and Bassanezi (2008)

HLB Spread Through a Grove of Trees

Through the information that can be gleaned by observing HLB spread in individual trees, an assessment of the spread through a group of trees can be made. The incidence of symptomatic trees (y) in year t can be estimated using the Gompertz function, (3.2) $$y_t = e^{-(-\ln(y_o))^{e^{-Rt}}},$$

where y_o is the portion of symptomatic trees when HLB symptoms first present themselves and R is the rate of disease incidence progress through a grove each year (Bassanezi and Bassanezi, 2008). Table 3.1 shows the values used for R, while y_0 can be set at varying values depending on the amount of acreage being examined (see Bassanezi and Bassanezi 2008; Salifu et al. 2012). The larger the area, the smaller the initial proportion of symptomatic trees, due to the fact that growers would be able to identify symptoms with the same initial amount of trees, regardless of the total amount of acreage. Figure 3.2 illustrates the results of estimating how quickly HLB would spread even when the initial proportion (y_o) of symptomatic trees is 0.01%. The younger the trees are, the faster the spread.

The distance and rate at which HLB can spread through a grove is dependent upon the abundance of inoculum (infected trees) and dispersion capabilities of ACP populations. HLB can disperse through an orchard at the same rate that ACP can. The rate of new tree infections is greatly dependent upon the initial amount of trees that were infected immediately upon HLB arrival (y_o). This is due to the fact that each infected tree is harboring the inoculum for ACP to become infected with and consequently spread HLB. The greater number of infected trees results in a greater chance for of psyllids to become infected with of HLB and causes a faster spread from tree to tree.

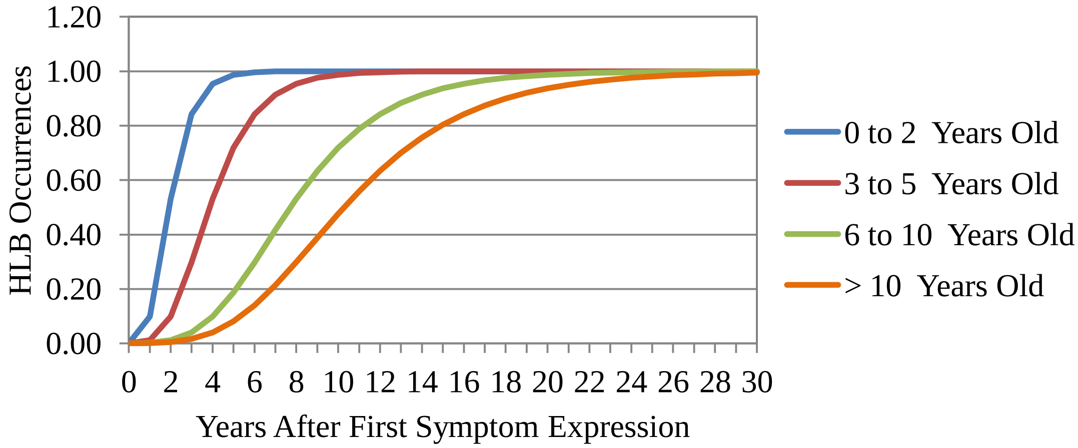

Figure 3.2. Estimated Proportion of HLB Infected Trees with an Initial Detection of 0.01%

The size of the grove being examined plays a role in estimating the incidence rate. One tree exhibiting symptoms in one acre amounts to a y_o of 8.26 x 10^{-3}, while one tree in 100 acres would create an incidence rate of 8.26 x 10^{-5}. This is why the incidence rate is not a fixed value. Figure 3.3 shows the different expected speed of HLB movement through a 10-year-old orchard at different rates of initial introduction of HLB and are exhibiting symptoms of the disease. Initial incidence rates represent the percent of trees that were infected at the first introduction of HLB. If there is an incidence rate of 0.01%, the number of HLB incidences would increase to 50% between years 5 and 6. With a lower initial infection rate of 0.0001%, the same level of HLB incidences would be reached in year 8.

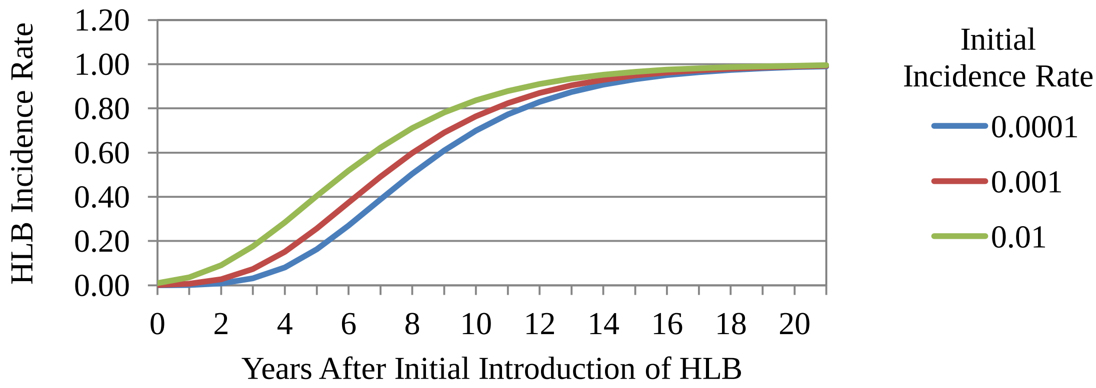

Figure 3.3. Initial Infection Rates Impact on HLB Incidence Progress Through a 10-Year-Old Block of Trees

HLB Implications on Orange Yields

Being able to assess the reduced yield of infected trees can play an important role in determining whether or not a grower would want to modify their cultural practices to limit the spread of HLB. Attempting to slow down the spread of HLB can be a costly endeavor between controlling ACP populations and identifying the diseased trees for removal. Depending on the age of a block of orange trees, diseased trees can potentially stay economically productive for years. When diseased trees are not removed, the immediate inoculum reservoir remains high, allowing for an increase in the spread of HLB.

Combining the individual tree disease severity and the HLB spread rate allows for an assessment of the expected yields per block to be made. Figure 3.4 illustrates the spread of HLB through individual trees and disease incidence over time (*N*). Although the spread rate and pattern does not necessarily represent the actual spread rate of a particular age group of trees, it provides an illustration of the dual spread pattern of HLB over time. Spread of HLB will continue in each tree until the entire canopy as well as every tree in the grove is infected. Both types of spread will have a negative impact on expected yields. Combining the individual tree infection proportion and the overall infection rate in the grove, the total disease severity for the grove can be estimated.

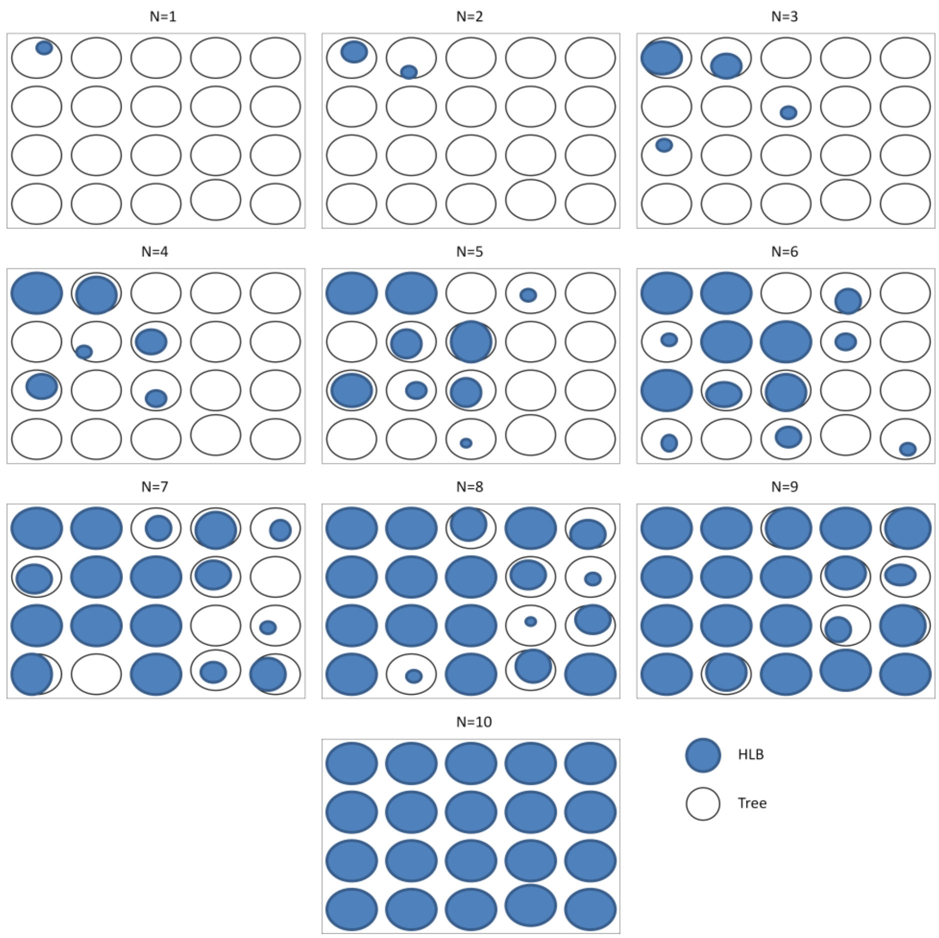

Figure 3.4. Visual of the Spread of HLB Within Individual Trees and Within a Block of Orange Trees Over Time

Total disease severity (*TD*) can be estimated as

(3.3) $$TD_t = \sum_{j=0}^{j=t} (y_j - y_{j-1})\, s_{t-j},$$

where *y* is the incidence of symptomatic trees (Equation 3.2) and *s* is the portion of the canopy exhibiting symptoms of HLB (Equation 3.1) (Bassanezi and Bassanezi, 2008). Equation 3.3 can be used to estimate the overall severity of HLB in a grove for any number of years (*t*) after an HLB introduction.

Once the total disease severity (*TD*) is calculated for any given year, it is used in a negative exponential model to approximate relative yield (Bassanezi and Bassanezi, 2008; Gottwald et al., 2010). That is,

(3.4) $$RY_t = e^{(-1.8TD_t)}.$$

The relative yield function above is used to compare HLB yields with yields from healthy trees (Bassanezi and Bassanezi, 2008). If the RY_t is 0.85, then a 15% decrease in production is expected during year *t*, as compared to that of healthy trees. Due to the fact that disease progress is dependent upon the severity level in prior years, RY_t is computed individually for each year. Notice that RY_t never reaches zero because it has been observed that even when a tree is considered to be completely infected (*s*=100%), it can still produce fruit. Although at this point the model predicts that fruit production will be minimum. Bassanezi et al. (2011) observed trees that were completely infected and still producing fruit, with a relative yield of up to 19%. While this is the case, there will come a point in time where the tree no longer produces fruit and dies from the HLB infection. The amount of time between full infection and tree necrosis is not addressed. By the time relative yield reaches such low levels, it is likely that producers will no longer be harvesting the crop that is present, as returns to growers will no longer cover to cost of production and/or harvesting.

Figure 3.5 illustrates how estimated yields would decrease upon HLB infection. If one tree in 180,000 acres (21,780,000 trees) is infected with HLB, total yields would decrease at different rates depending on the age of the tree. As the disease severity in each tree decreases production, HLB would continue to spread through the 180,000 acres. If the trees are all young (2 years old or less), production will continue to increase for a few years, since all the trees are not infected at the initial introduction. Whereas, if trees are over 10 years old, overall production losses would not begin to be felt until after year four or five. Bassanezi and Bassanezi (2008) believe this is one of the reasons why farmers with older trees are harder to convince to take an active stand against limiting the spread of HLB. In fact, because HLB infected trees over 10 years old continue to be productive for many years, many growers may refuse to remove them.

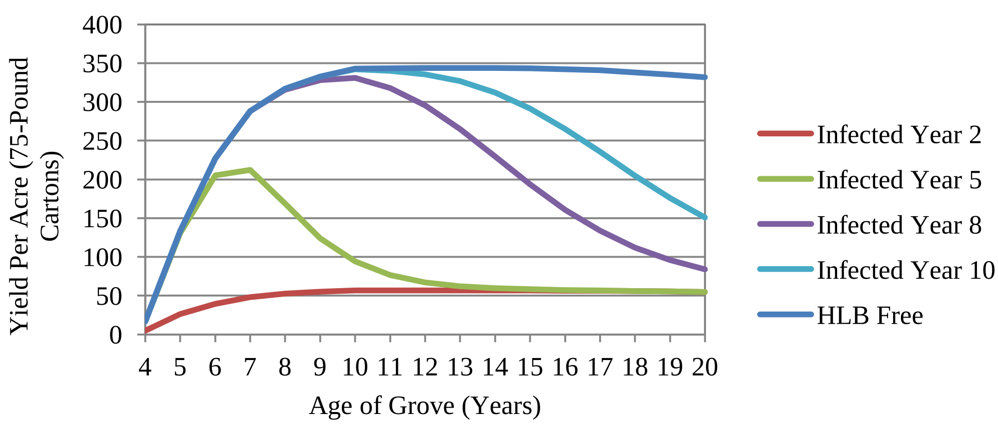

Figure 3.5. Estimated Orange Yields Per Acre

HLB Impact on California Orange Yields Over Time

There are currently around 180,000 bearing acres of oranges in California (USDA, 2011g). Figure 3.6 shows that of these 180,000 acres, approximately 86% are over 10 years old and 9% fall into the age category of 6 to 10 years old (California Agricultural Statistics Service, 1999;

2002; USDA, 2006; 2008; 2010; 2011g; Computed by Author). In recent years there has been a decrease in orange grove acreage being planted and overall bearing acreage has been declining (USDA, 2010a; 2011g). Since the average age of orange trees in California are older, HLB is predicted to spread at a slower rate than if 50% of the trees were in a younger age category.

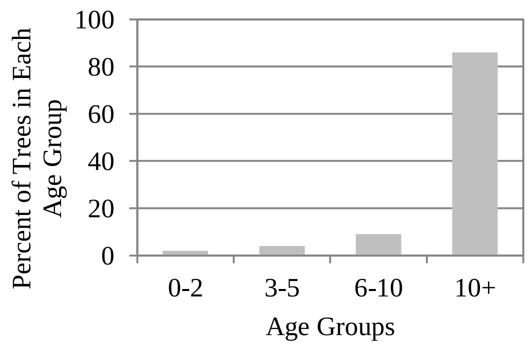

Figure 3.6. Percent of Trees in Each Age Group in California

Source: California Agricultural Statistics Service (1999; 2002) and USDA (2006; 2008; 2010; 2011g). Computed by Author.

Many factors influence when an orange tree begins producing oranges, including but not limited to, the age of the tree, nutritional programs, and the tree spacing in the orchard. Different tree densities per acre can be selected depending on the ultimate goals of the farmer. Tree densities can be selected depending on whether early production is desired or larger canopy size to maximize production when the tree is mature is desired (Tucker et al., 1994). This study uses a constant average density of 121 trees per acre and a bearing age of 4 years. While trees will show some production in the fourth year after planting, a noticeable contribution to total yields will not generally be seen until the fifth year. This study also assumes that production increases until the tree reaches 10-15 years old and then it reaches a plateau, which follows the normal production cycle of citrus trees in California (refer to HLB Free line, Figure 3.5).

Bassanezi and Bassanezi (2008) assumed that the entire grove was in the same age bracket. Since the orange trees in California are not all in the same age bracket (Figure 3.6), this study accounts for the variability in the age of trees by using a stochastic simulation model. A stochastic simulation model is appropriate because it takes into account different parameters from each age group that determine the rate of spread of HLB and estimates the total expected damage of HLB over time. The parameters are considered biological because they are used in the model to explain disease progression, which is a biological process. These parameters include the proportion of HLB symptom expression in individual trees, and the annual rates of both HLB progress in individual trees and through the state. The values for the biological parameters included in the model are presented in Table 3.2.

Table 3.2. Biological Parameters Included in the Pessimistic Approach

Parameter	Definition	PERT Values		
		Minimum	Most Likely	Maximum
s_o	Proportion of HLB symptom expression in individual trees*	2.55×10^{-2}	3.75×10^{-6}	0.10
r	Annual rate of HLB progress in an individual infected tree	0.69	0.69	1.84
R	Annual rate of HLB incidence progress through the state	0.23	0.23	0.65

Note: Information regarding PERT distributions can be found in Appendix A.
*These values are proportions, meaning that 0.10=10%.

Simulation

Using the rates of spread of HLB through the different age groups presented by Bassanezi and Bassanezi (2008), each parameter can be simulated using PERT distributions.[1] These include

[1] Additional information regarding the PERT distribution is provided in Appendix A.

values for the proportion of symptom expression in individual trees (s_o), annual rates of HLB progress in individual trees (r), and the annual rate of HLB incidence progress through a block of oranges (R). This allows for the consideration of a range of possible values for the parameter, rather than a stagnant value. The PERT distribution differs from a normal distribution. The shape of a PERT distribution is determined by the minimum value, the most likely value, and the maximum value. The shape of a normal distribution is determined by its mean and standard deviation.[2]

With the majority of trees in California being 10 years or older, the minimum and most likely values in the PERT distribution are appropriately estimated by the parameter values reported by Bassanezi and Bassanezi (2008) for trees greater than 10 years old. That is, the PERT distribution allows for a better fit of the actual distribution of the age of the trees in California than a normal distribution because the distribution of the age of the trees in California is skewed left (see Figure 3.6).

The parameter values in Table 3.2 are used in Equations 3.1 through 3.4 to assess the yield implications under the pessimistic scenario. According to the annual summary of citrus production data published by the USDA (2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g), the average yields between 2000 and 2011 range from 242 to 354 cartons per acre per year, where each carton weighs 75 pounds. This study uses a uniform distribution to consider expected yield values between 242 and 354 cartons when HLB is not present.[3] The use of a uniform distribution is appropriate because yield values from 2000 to 2011 have been fluctuating between 242 and 354 cartons per acre (as seen in Figure 1.9). This allows for a wider range of possible yields to be considered in the simulation, rather than just a single yield value.

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[2] Additional information regarding the normal distribution is provided in Appendix A.
[3] Additional information regarding the uniform distribution is provided in Appendix A.

In other words, any value between 242 and 354 cartons per acre is randomly chosen with the same probability of being selected. Then, the expected yield (EY_t) from diseased trees at year *t* is estimated by multiplying the expected yield from healthy trees at year *t* (HY_t), which are generated from a uniform distribution, by the relative yield (RY_t) that would be obtained from diseased trees in year *t* (Equation 3.5). That is, the expected yield from diseased trees is estimated by

(3.5)
$$\begin{aligned} EY_t &= HY_t \times RY_t \\ &= UNIFORM(242, 354)_t \times RY_t. \end{aligned}$$

Once the values for the expected yield for each year as HLB progresses through the state are estimated, they are incorporated with the percentage that will be processed (k_t),

(3.6)
$$\begin{aligned} Y_{pt} &= EY_t \times k_t \\ &= EY_t \times UNIFORM(0.13, 0.291)_t, \end{aligned}$$

where Y_{pt} is the yield that will be processed. The yield that will be sold as fresh oranges is

(3.7)
$$Y_{ft} = EY_t - Y_{pt}.$$

To account for the variability in what percentage of the harvested crop goes to processing and what remains as fresh fruit, a range of values for the percent that are processed (k_t) is considered. In the last 20 years the average minimum value is approximately 13.0% and the average maximum value is approximately 29.1% (USDA, 1994; 1995; 1996; 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g). This study uses a uniform distribution to consider potential values for the percent-processed rate between 0.130 and 0.291 (Equation 3.6). The use of the uniform distribution is appropriate because the percent-processed values from 2000 to 2011 have been fluctuating between 13.0% and 29.1% as seen in

Figure 1.10. The use of a uniform distribution means that any percent-processed rate within the range considered has an equal chance of being selected in each of the iterations in the simulation.

The prices for both fresh (P_{ft}) and processed oranges (P_{pt}) at year t are estimated using price ranges from year 2001 to year 2008 and are incorporated in the simulation. The processed-orange price ranges from $0.23 to $1.52 per 75-pound carton while the fresh-orange price ranges from $9.26 to $18.01 per 75-pound carton (USDA, 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a). These prices represent the value of the fruit when it leaves the packing house door. In the simulation analysis, the fresh orange price was assumed to be normally distributed with a mean of $12.73 and a standard deviation of $1.16 from year 1 to year 20. Similarly, the processed orange price was assumed to be normally distributed with a mean of $0.76 and a standard deviation of $0.25 from year 1 to year 20. An estimated 99.7% of the values from the 10,000 iterations will be between $9.25 and $16.21 per 75-pound carton for the fresh orange price and between $1.52 and $0.00 per 75-pound carton for the processed orange price. These price values are incorporated into the simulation analysis by using normal distributions (Equation 3.8). The use of the normal distribution for orange prices is appropriate because the average annual prices seen for all oranges in California between 1992 and 2011 were relatively stable, as seen in Figure 1.11. The total value of production (TP_t) at year t is estimated by

$$TP_t = P_{ft} \times Y_{ft} + P_{pt} \times Y_{pt} \tag{3.8}$$

$$= NORMAL(12.73, 1.16)_t \times Y_{ft} + NORMAL(0.76, 0.25)_t \times Y_{pt},$$

where P_{ft} is the price of fresh oranges, Y_{ft} is the estimated yield being sold as fresh fruit, P_{pt} is the price of processed oranges, and Y_{pt} is the quantity of oranges being sold for processing, all at year t. The variables P_{ft}, Y_{ft}, P_{pt}, and Y_{pt} are all denoted on a per acre basis, based on a 75-pound carton. Table 3.3 summarizes the range of values that were used to incorporate these variables in the analysis as uniform distributions (yields) and normal distribution (prices).

The total production value per acre (TP_t) as HLB spreads through the state over time is incorporated into the simulation as

$$TL_t = HP_t - TP_t, \quad (3.9)$$

where the total loss during year t (TL_t) is equal to the expected value of production with no HLB (HP_t) minus the estimated value of production with HLB (TP_t). The expected value of production with no HLB is estimated as

$$HP_t = \left(HY_t \times k_t \times P_{pt}\right) + (HY_t \times (1 - k_t) \times P_{ft}). \quad (3.10)$$

The present value of the simulated losses in production value over the T year period considered is computed as

$$PV_{Loss} = \sum_{t=1}^{T} (1 + i)^{-t} \times TL_t. \quad (3.11)$$

Since this study is interested in today's value of the loss in production, accounting for the time value of money is needed. The value of $1,000 received twenty years from now is not expected to be worth the same as $1,000 received today.

Table 3.3. Minimum and Maximum Yields and Percent Processed Rate and Fresh Orange Price and Processed Orange Price Mean and Standard Deviation during 2000-2011

Parameter/Variable	Values	
	Minimum	Maximum
Expected Healthy Yields*	242	354.00
Percent Processed	13.0%	29.1%
	Mean	Standard Deviation
Fresh Orange Price*	$12.73	$1.16
Processed Orange Price*	$0.76	$0.25

Note: Values based off of historical values between 2000-2011 crop years.
* Values are based on 75-pound cartons.

Source: USDA (2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g). Computed by Author.

In order to estimate the present value of the total loss in production under the pessimistic approach, a Monte Carlo simulation of Equation 3.11 will be run 10,000 times.[4] This will be done using RiskAMP, a simulation add-in in Microsoft Excel that handles PERT distributions, normal distributions, and uniform distributions. At each iteration, the parameters s_o, r, R, and k_t and the variables HY_t, P_{ft}, and P_{pt} are randomly generated based on their individual distributions. This provides 10,000 different possible outcomes of the final net present value of the expected loss after 20 years after the introduction of HLB in California. The simulation analysis allows for taking into consideration a range of likely values. After the model is simulated 10,000 times, the present value of the loss in production value under the pessimistic scenario is estimated (Equation 3.11). Table 3.4 and Figure 3.7 summarize the names and the notation of the variables

[4] Monte Carlo simulations are employed to account for the stochastic nature of the variables and parameters used in each approach. Deterministic simulations, an alternative to stochastic simulations, are used when the model inputs are known and not variable or uncertain. Therefore, Monte Carlo simulations were selected.

and parameters included in the pessimistic approach. Figure 3.8 summarizes the equations used in the pessimistic approach.

Table 3.4. Summary of Variables and Parameters Used in the Pessimistic Approach

Variable	Definition
s_t	Proportion of HLB severity in an individual tree in year *t*
y_t	Incidence of symptomatic trees per acre in year *t*
TD_t	Total disease severity per acre in year *t*
RY_t	Relative yield per acre in year *t*
EY_t	Expected yield with diseased trees per acre in year *t*
HY_t	Expected healthy yield in 75-pound cartons per acre in year *t*
Y_{ft}	Fresh orange yield in 75-pound cartons per acre with HLB in year *t*
Y_{pt}	Processed orange yield 75-pound cartons per acre with HLB in year *t*
P_{ft}	Price per 75-pound carton of fresh oranges in year *t*
P_{pt}	Price per 75-pound carton of processed oranges in year *t*
TP_t	Total value of production in dollars with HLB in year *t*
HP_t	Total value of production in dollars without HLB in year *t*
TL_t	Total loss in production in dollars value due to HLB in year *t*
PV_{Loss}	Present value of loss in production value due to HLB in dollars

Parameter	Definition
s_o	Proportion of HLB symptom expression in individual trees
r	Annual rate of HLB progress in an individual infected tree
R	Annual rate of HLB incidence progress through a grove
y_o	Portion of symptomatic trees at the onset of symptom expression
k_t	Percent processed rate

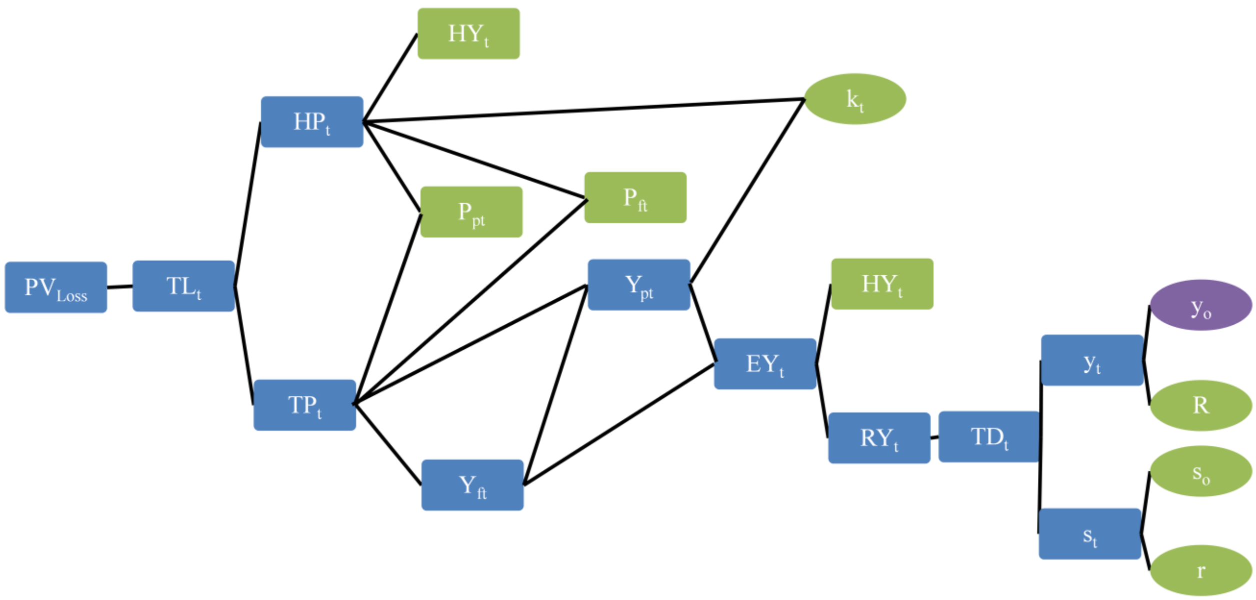

Figure 3.7. Summary of the Variables and Parameters Used in the Pessimistic Approach

Note: Rectangles denote variables, ellipses denote parameters, equations are illustrated in the color blue, distributions are illustrated in the color green, and constants in the color purple.

$$PV_{Loss} = \sum_{t=1}^{T} (1+i)^{-t} \times TL_t$$

$$TL_t = HP_t - TP_t$$

$$HP_t = \left(HY_t \times k_t \times P_{pt}\right) + \left(HY_t \times (1 - k_t) \times P_{ft}\right)$$

$$TP_t = P_{ft} \times Y_{ft} + P_{pt} \times Y_{pt}$$

$$Y_{ft} = EY_t - Y_{pt}$$

$$Y_{pt} = EY_t \times k_t$$

$$EY_t = HY_t \times RY_t$$

$$RY_t = e^{(-1.8TD_t)}$$

$$TD_t = \sum_{j=0}^{j=t} \left(y_j - y_{j-1}\right) s_{t-j}$$

$$y_t = e^{-(-\ln(y_o))^{e^{-Rt}}}$$

$$s_t = \frac{1}{1 + \left(\left(\frac{1}{S_o} - 1\right) e^{-rt}\right)}$$

Figure 3.8. Summary of the Equations Used Under the Pessimistic Approach

The Optimistic Approach

Although in some instances, no widespread attempts to limit the incidence of HLB are made, it is not the norm. Through modifying cultural practices, the rate of spread of HLB can be kept below 1% (Morris and Muraro, 2008; Roistacher, 1996). With many different options available to growers, it is likely that the rate of spread will fluctuate somewhat, depending on the intensity of the control program being implemented. With an aggressive HLB control strategy in place, yields can remain stable enough to keep the industry afloat.

With ACP populations established throughout the state, under this approach, if HLB is discovered it will be expected that immediate attempts to limit the spread of the disease will take place. This includes the beginning of conducting HLB field surveys and increasing pesticide applications in an attempt to minimize ACP population levels throughout the state. As HLB spreads throughout California, costs associated with diseased tree removal and replacement, in addition to decreased yields will be realized. While the intensity of attempting to limit HLB spread will vary between individual growers, the optimistic approach assumes that all growers in the state will be taking an active approach.

Total Damages

The total damage costs of HLB in dollars per acre (D_t) are comprised of two separate components, the total loss in production value per acre (RV_t) and the additional costs associated with limiting HLB spread per acre (AC_t) as seen in Equation 3.17. That is, the total damage costs of HLB are

(3.12) $$D_t = RV_t + AC_t,$$

where

(3.13) $$RV_t = HP_t - OP_t,$$

where HP_t is the value of the estimated healthy yield in dollars in year t (Equation 3.10) and OP_t is the value of the estimated yield in dollars in year t under the presence of HLB. OP_t is estimated as

(3.14) $$OP_t = P_{ft} \times Y_{ft} + P_{pt} \times Y_{pt}$$
$$= NORMAL(12.73, 1.16)_t \times Y_{ft} + NORMAL(0.76, 0.25)_t \times Y_{pt},$$

where P_{ft} is the price of fresh oranges in year t, Y_{ft} is the amount of cartons per acre sold as fresh oranges in year t post HLB, P_{pt} is the price of processed oranges in year t, and Y_{pt} is the expected yield under the presence of HLB that is sold as processed fruit in year t. Both the prices for fresh and processed oranges are assumed to be normally distributed and hold the same mean and standard deviation as the pessimistic approach (see Table 3.3).

The number of cartons per acre that are produced under the presence of HLB that are sold as processed oranges (Y_{pt}) are estimated as

(3.15) $$Y_{pt} = TY_t \times k_t$$
$$= TY_t \times UNIFORM(0.13, 0.291)_t,$$

where TY_t is the total yield per acre in year t post HLB (see Equation 3.22) and k_t is the proportion of the yield that is sold as processed oranges. The percent-processed (k_t) is assumed to have a uniform distribution, just as seen in Equation 3.6 in the pessimistic approach. The minimum and maximum values for k_t are shown in Table 3.3. This leaves the proportion of the total yield per acre in year t post HLB that is sold as fresh fruit (Y_{ft}) to be equal to

(3.16) $$Y_{ft} = TY_t - Y_{pt},$$

where TY_t is the total yield per acre in year *t* post HLB (see Equation 3.22) and Y_{pt} is the amount of expected yield under the presence of HLB that is sold as processed fruit in year *t* (Equation 3.15).

In the optimistic approach, immediate changes will be made to limit HLB spread upon initial detection. This is accompanied with costs that are dependent upon the rate of spread of HLB. This is estimated as

(3.17) $$AC_t = \Delta FC + RT_t + PT_t,$$

where AC_t is the total additional costs incurred per acre in year *t* as a result of HLB, ΔFC is the immediate per acre increase in fixed production costs, RT_t is the cost associated with the diseased tree removal in year *t*, which depends on the rate of spread of HLB (see Equation 3.18), and PT_t is the total per acre cost of replanting trees in year *t* that were removed the previous year.

The costs associated with the removal of HLB symptomatic trees include two separate components. The first component consists of the direct cost of having to remove the tree (RT_t) and the second component consists of the direct cost of replacing it (PT_t). That is, the first component is estimated as

(3.18) $$RT_t = CR \times OL_t,$$

where CR is the tree removal cost and OL_t is the number of trees removed in year *t*, while the second component is estimated as

(3.19) $$PT_t = CP \times OL_{t-1},$$

where CP is the cost of a replacement tree and OL_t is the number of trees that were removed in year *t*.[5] It is assumed under the optimistic approach that all trees removed in year *t* are replaced with new trees the following year. The number of trees removed each year is dependent upon the rate of HLB spread in year *t*. This rate of HLB spread (R_t) is estimated using a PERT

[5] OL_t is defined in Equation 3.20.

distribution, just as in the pessimistic approach.[6] The use of the PERT distribution is appropriate to estimate the rate of spread of pests and diseases, as it has been used in other disease spread models (Cook et al., 2007 and Cook and Matheson, 2008). The values assumed in the PERT distribution for the annual rate of HLB spread are different in the optimistic approach, than what were used under the pessimistic approach. The values are different from the pessimistic approach because it is assumed under the optimistic approach that orange growers attempt to keep the HLB spread rate as small as possible. The optimistic values for the annual spread rate are estimated to be 0.010, 0.023, and 0.032 for the minimum, most likely, and maximum values respectively.

Morris and Muraro (2008) and Roistacher (1996) have documented that the rate of spread can be kept at 0.010, therefore this will be the minimum value (a). Morris et al. (2008) and Morris and Muraro (2008) report that the rate of spread of HLB in Florida under attempts to limit it, have been observed to average 0.023, therefore this value was adopted for the most likely value (b) in the PERT distribution assumed for the annual rate of spread. The National Research Council (2010) reports the rate of spread as high as 0.04. A lower value for the maximum rate of spread of HLB than the 4% reported was assumed under the optimistic approach due to the fact the 4% came from studies where mixed management practices were adopted by growers and a uniform attempt at controlling the rate of spread of HLB was not made.

Another cost associated with removing diseased trees is the opportunity cost of removing diseased but still productive trees. When you remove a diseased tree that is still productive, growers wait for a minimum of four years to see any production in the replacement tree. This can be quantified as the reduction in yields from removing diseased trees (DY_t). Multiplying the

[6] The PERT distribution allows for a better fit of the actual distribution of the age of the trees in California than a normal distribution because the distribution of the age of the trees in California is skewed left (see Figure 3.6).

healthy yield in 75-pound cartons in year t (HY_t) by the proportion of trees that are removed in one acre (i.e. $OL_t/121$, where 121 is the number of trees planted per acre) estimates the reduction in yields from removing diseased trees in year t. That is, the reduction in yields from removing diseased trees is estimated as

(3.20)
$$DY_t = \frac{OL_t}{121} \times HY_t,$$
$$= \frac{\left(\frac{R_t \times HY_t}{HY_t/121}\right)_t}{121} \times UNIFORM(242, 354)_t.$$

Other factors such as early fruit drop off and reduced initial fruit set can also contribute to reduced yields under the presence of HLB. This form of yield loss is not taken into account due to the fact that the optimistic approach assumes that all trees identified with HLB will be immediately removed.

Since one of the specific objectives of this study consists of examining the costs that could be avoided by keeping HLB from becoming endemic in California, the possible costs associated with its presence are examined. The costs that are taken into account consist of scouting for the disease (SC), removing the diseased trees in year t (RT_t), replanting removed trees with replacement trees in year t (PT_t), and managing ACP (SP), which mainly consists of applying additional pesticides. Clearly, not all the costs associated with the presence of HLB are included in this assessment. Some additional costs derived from HLB establishment, including managerial and management implementation costs, are not included in the analysis, as there is little (if any) information available about these costs.

This optimistic approach assumes that as soon as the first detection of HLB is made in California, a state wide attempt to limit its spread will immediately follow. The immediate increase in fixed production costs per acre (ΔFC) associated with this assumption include scouting costs for HLB symptomatic trees (*SC*) and costs of increasing pesticide applications (*SP*). That is,

(3.21) $$\Delta FC = SP + 4SC.$$

What happened in Florida's citrus industry is a good example of what could happen to California's citrus industry if a statewide management program is not initiated upon initial detection of HLB. The only current known way to limit the HLB damage is to take immediate action upon detection, with attempts to limit ACP population growth and reduce the amount of inoculum available.

Scouting. Scouting is required in order to assess the number of HLB incidences. This entails examining all the trees in the grove. Scouts examine the entire tree canopy looking for some form of symptom expression. Scouting can be conducted in a variety of ways, including on foot or horseback, or using, all terrain vehicles (ATV), pickup trucks or tractors. The number of people that partake in this disease detection varies and depends on the available resources. Since the costs associated with each type of scouting practice vary, the optimistic approach considers a range of likely values.

Due to the long latency period of HLB, it is important to continually identify any trees exhibiting new symptoms. Once identified, these trees need to be removed immediately. Removing the source of inoculum is necessary to limit the HLB spread. Morris et al. (2008) recommend scouting a minimum of four times per year. In Florida, Morris and Muraro (2008) report scouting costs (*SC*) range from $14 to $35 per acre. With 4 inspections per year (4x*SC*), the annual cost of scouting ranges from $70 to $140 per acre.

Since HLB is not currently found in California, there are no values that can be attributed to scouting costs. To estimate scouting costs, this study assumes that the costs are going to be similar as the ones seen in Florida. To account for the disparity between the monetary value of labor in Florida and California, an adjustment is made by evaluating the differences in minimum wage between the two states. Following the principles of purchasing power parity (PPP), as done when comparing the differences in purchasing power for the same good between two locations, estimates for scouting costs in California can be derived.

In 2011, the minimum wage in Florida and California was $7.25 and $8.00 per hour respectively (United States Department of Labor, 2012). Applying the percentage difference between the two wage rates to the established range in Florida's scouting costs, which range from $14.00 to $35.00 per acre, California's scouting costs are estimated to range from $15.45 to $38.62 per acre. Through assessing various studies conducted in Florida, average reported scouting costs (adjusted for PPP) are estimated to be $27.22 per acre (Irey et al., 2008; Morris and Muraro, 2008; National Research Council, 2011). When scouting is conducted four times per year, scouting costs are estimated to be $108.88 per year per acre (Irey et al., 2008; Morris and Muraro, 2008; National Research Council, 2011). The annual cost of scouting is summarized in Table 3.5.

ACP Control. Controlling ACP populations is an integral part of HLB management due to its vector capabilities. The density of ACP populations plays a critical role in determining how to treat for the pest. This is why it is crucial to understand the dispersion capabilities of ACP and how to determine the densities in individual groves.[7] Dependent upon the time of year and grower preferences, a variety of different foliar insecticides are available for use. These treatment applications are generally made in addition to what is already being done under the non-presence of HLB. There are direct and indirect costs related to these additional pesticide applications. Some expected indirect costs are related to the balance of the ecosystem in the grove. When applying pesticides, not only will ACP populations be reduced, but beneficial

[7] ACP dispersion capabilities and ACP densities in individual groves is discussed in Chapter 2.

insect populations will also be decreased. The actual costs associated with purchasing and applying pesticides are not fully reflected in the cost of the product and the cost of applying pesticides. Due to time constraints this study excludes these environmental costs, as only direct costs are being examined.

There are numerous possibilities available when implementing an ACP control program. The number of insecticide applications and what type of product used can create a wide disparity in the costs. The purchase and application costs of three additional foliar insecticide applications per year and one soil application of aldicarb (a systemic insecticide) are going to make up the costs related to ACP Control. Morris et al. (2008) recommend three foliar applications and one soil application per year. Since there is a large variation in the number of applications producers make, the value used in this study can be considered a baseline, as costs can go up or down from there. Costs can go higher, if growers choose to apply additional pesticide applications. The optimistic approach only assumes that the recommended number of sprays are conducted. A value of $317.59 per acre for the costs related to ACP control will be used in the optimistic approach (see Table 3.5). Costs may also go down if new cost-saving technology is introduced.

Although some growers choose to apply foliar nutrients to the tree canopy, this method has not been adopted by the mainstream and will not be considered under the optimistic approach. The reasoning behind not including these costs is due to the fact that foliar nutritional sprays are usually targeted at HLB infected trees that are not removed. By applying a nutritional spray directly on the canopy, an infected tree can receive nutrition that is limited as a result of HLB infection since HLB is a phloem limiting bacterium. Since the approach being examined here calls for diseased tree removal, these costs are not applicable.

Tree Removal and Tree Replacement. Upon identification of infected trees, most experts recommend immediate removal. Costs associated with tree removal include uprooting the tree, disposing of the tree, ground preparation for replanting and the direct cost of the replacement tree. The number of trees planted per acre can vary, but will be held at 121 trees per acre in this study.[8] Removed trees will be replaced with new plantings the year after their removal (see Equation 3.19). By removing the diseased trees, the amount of inoculum available to infect additional ACP and spread HLB is greatly reduced.

The costs associated with tree removal vary depending on the number of trees that are being removed. Not only is removal and disposal of the tree required, but so is preparing the now fallow ground for replanting. Table 3.5 reports removal and ground preparation costs, which are estimated at an average of $13.34 per removed tree (Irey et al., 2008; Morris and Muraro, 2008; O'Connell et al., 2009). The current cost of replacement trees in California is estimated at $10.50 per tree (O'Connell et al., 2009). As the demand for nursery stock increases and the costs associated with nursery stock production increase, it is expected that the price for replacement trees will increase. The level of demand for replacement trees outweighs the availability, as was the case in Florida. Since the introduction of HLB in Florida, the cost of replacement trees in Florida has doubled (National Research Council, 2010). This study assumes that the cost of replacing trees in California will follow a similar trend. Therefore, a value of $21.00 per replacement tree is assumed in this study (see Table 3.5).

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[8] The number of orange trees per acre varies throughout the state. An average of 121 trees per acre is used in the optimistic approach.

Table 3.5. Annual Costs Associated with Limiting HLB Spread

Variable	Values	
	Per Acre	Per Tree
ACP Control (AC_t)	\$317.59	
Scouting (*SC*)	\$108.88	
Tree Removal (*CR*)		\$13.34
Tree Replacement (*CP*)		\$21.00

Yield Reduction

It has been shown that under consistent and stringent management practices for HLB, an average increase in tree removal of 2.3% is possible (Morris et al., 2008). While smaller values can be obtained, the required intensity of management practices is not usually seen in a widespread fashion. It has been observed that upon initial detection of HLB, the number of diseased trees that require removal will be high. Once management practices attempt to limit the spread of HLB, the number of diseased trees detected at each scouting is expected to decrease and hold steady.

Total yield per acre in 75-pound cartons with the presence of HLB can be estimated for each year. Total yield per acre is estimated as

$$TY_t = HY_t - DY_t - DY_{t-1} - DY_{t-2} - DY_{t-3} - DY_{t-4} - DY_{t-5}, \tag{3.22}$$

where HY_t is the expected healthy yield in 75-pound cartons per acre in year *t* and DY_t is the yield reduction in 75-pound cartons per acre from removing diseased trees for year *t* (Equation 3.20). Replacement trees are planted a year after the removal of diseased trees to keep the total number of trees planted per acre at 121 trees. Replacement trees will take four years to be considered to have any level of production. The loss of a single tree will not only be felt the year it was removed (DY_{t-5}) and the year it is replaced (DY_{t-4}), but also for the next four years after replacement (DY_{t-3}, DY_{t-2}, DY_{t-1}, DY_t) until it becomes productive. The expected healthy yield for each year and the subsequent decreased yields will be simulated 10,000 times, just as in the optimistic approach. Table 3.6 and Figure 3.9 summarize the names and the notation of the variables and parameters included in the optimistic approach.

Table 3.6. Summary of Variables and Parameters Used in the Optimistic Approach

Variable	Definition
PV_{Damage}	Present value in dollars of the total damage of HLB
D_t	Total damage in dollars per acre in year *t*
HP_t	Value of healthy yield in dollars per acre in year *t*
OP_t	Value of HLB yields in dollars per acre in year *t*
AC_t	Additional costs in dollars per acre associated with limiting HLB spread in year *t*
HY_t	Healthy yield in 75-pound cartons per acre in year *t*
P_{pt}	Price of processed oranges in 75-pound cartons in year *t*
P_{ft}	Price of fresh oranges in 75-pound cartons in year *t*
Y_{ft}	Fresh yield in 75-pound cartons with HLB in year *t*
Y_{pt}	Processed yield in 75-pound cartons with HLB in year *t*
ΔFC	Immediate increase in fixed costs in dollars per acre due to HLB in year *t*
RT_t	Direct cost of removing diseased trees in dollars per acre in year *t*
PT_t	Total cost of replanting trees in dollars per acre in year *t*
SP	Spray costs in dollars per acre
SC	Scouting costs in dollars per acre
OL_t	Number of trees lost per acre from HLB in year *t*
CR	Tree removal costs in dollars per tree
CP	Tree replacement costs in dollars per tree
RV_t	Value of total reduced yield in dollars per acre due to HLB
TY_t	Total yield in 75-pound cartons per acre with HLB in year *t*
DY_t	Yield reduction in 75-pound cartons acre due to HLB in year *t*

Parameter	Definition
R_t	Annual rate of HLB spread in year *t*
k_t	Percent Processed in year *t*

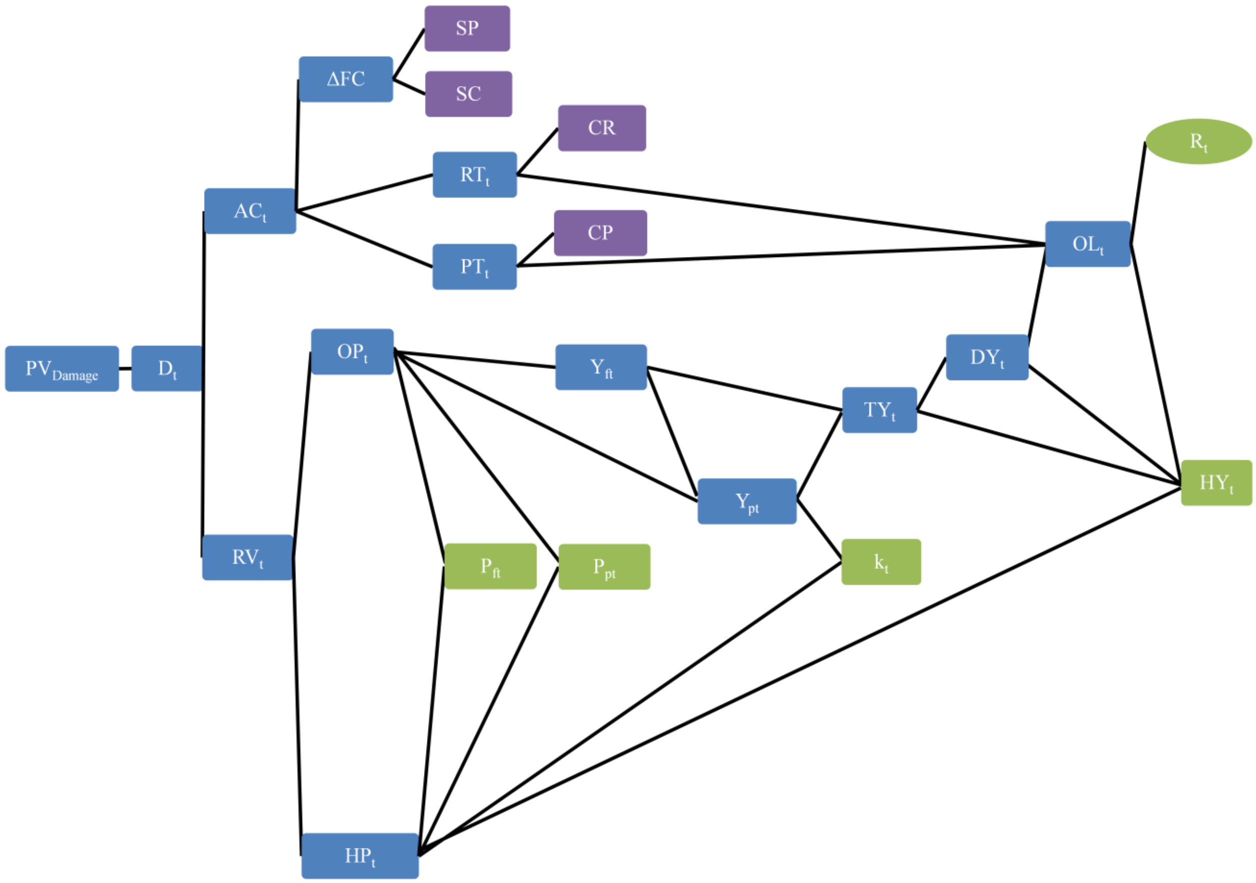

Figure 3.9. Summary of the Variables and Parameters Used in the Optimistic Approach

Note: Rectangles denote variables, ellipses denote parameters, equations are illustrated in the color blue, distributions are illustrated in the color green, and constants in the color purple.

Simulation

Once all the variables (HY_t, P_{pt}, P_{ft}, SP, SC, CR, and CP) and parameters (R_t and k_t) that make up the total damage cost (D_t) are determined, the total estimated damage caused by the presence of HLB (D_t) is estimated through Equation 3.12. That is, Equation 3.12 is simulated to estimate the present value of the total loss in production value combined with the costs of keeping HLB from spreading over time. Equation 3.12 is simulated to allow for the variability in the parameter values (R_t and k_t) and variables, including the estimated healthy yield (HY_t), the estimated price for processed oranges (P_{pt}), and the estimated price for fresh oranges (P_{ft}). Finally, the present value of the total damage costs is estimated to determine today's value of the production loss. That is,

(3.23) $$PV_{Damage} = \sum_{t=1}^{T} (1+i)^{-t} \times D_t,$$

where D_t is calculated using Equation 3.12. The present value of the simulated per acre loss due to the presence of HLB (D_t) is estimated to determine the value of those losses today.[9]

Just as in the pessimistic approach, 10,000 iterations are considered. This will be done using RiskAMP, a simulation add-in in Microsoft Excel that works with PERT distributions, normal distributions, and uniform distributions. During each iteration, the variables HY_t, P_{pt}, and P_{ft}, and the parameters R_t, and k_t are randomly generated based on the assumed distributions. This provides 10,000 different possible outcomes of the final net present value of the estimated total damage after 20 years after the introduction of HLB in California. Figure 3.10 summarizes the equations used in the optimistic approach.

[9] Present value (PV) is calculated by $PV=FV(1+i)^{-t}$, where FV is the future value, i is the discount rate, and t is the number of years. This allows for computing the present value of future dollars, in this case, the present value is in 2012 dollars.

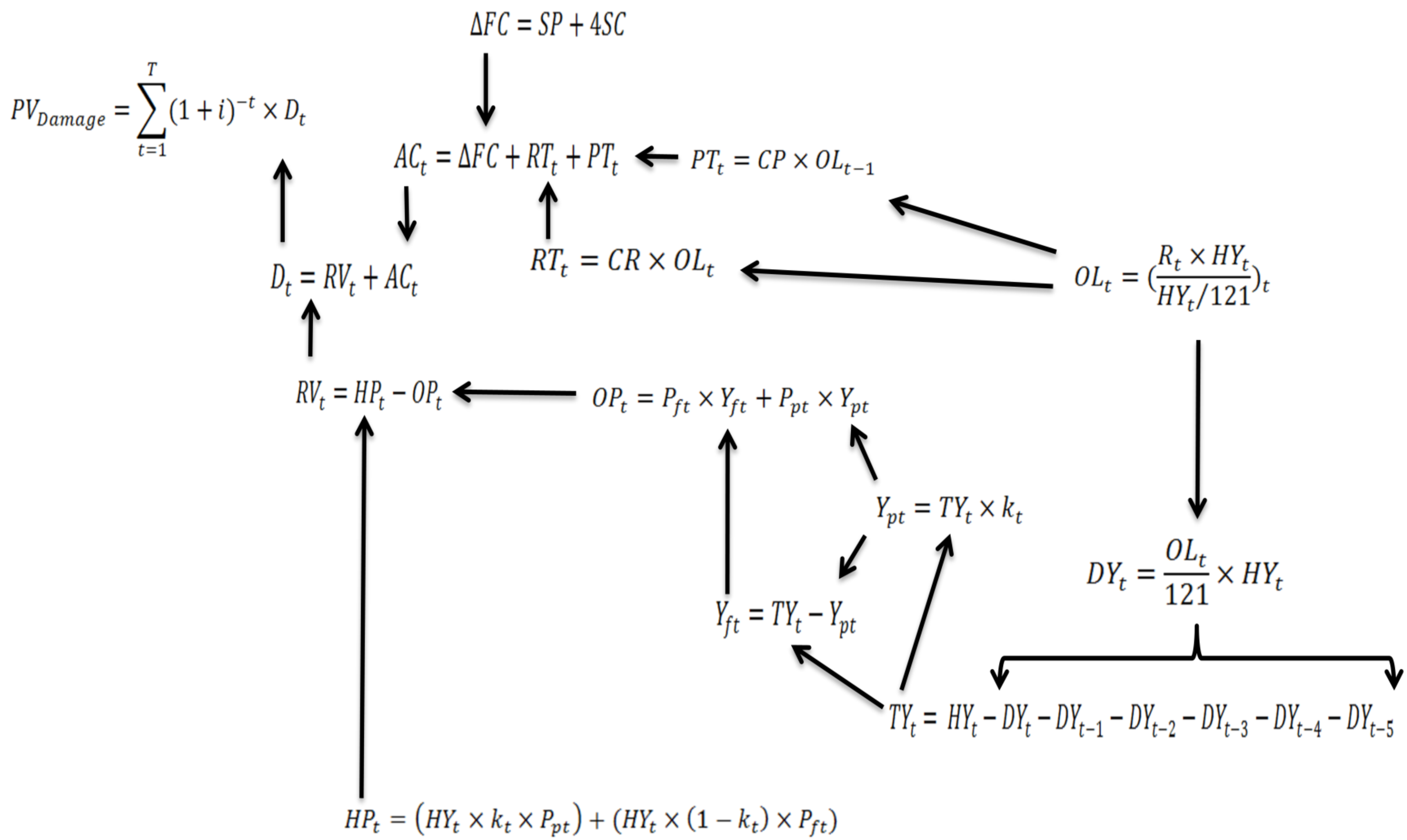

Figure 3.10. Summary of the Equations Used Under the Optimistic Approach

Data

Values included in the pessimistic approach, including the proportion of HLB symptom expression in individual trees (s_o) and the annual rate of HLB progress in individual infected trees (r) and through a grove of trees (R), have been obtained from empirical studies compiled by Bassanezi and Bassanezi (2008). These values are proportions. For example, an annual HLB progress rate in an individual infected tree of 0.10 means the area of the tree that is infected grows annually by 10%.

Under both approaches, yields (Y_{ft} and Y_{pt}), prices (P_{ft} and P_{pt}) and utilization rates of fresh ($1-k_t$) and processed (k_t) are all obtained from the annual *Citrus Fruits Summary* publications that are released by the National Agricultural Statistics Service (NASS), an agency within the United States Department of Agriculture (2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g). All values were compiled for orange production in the state of California. The processed quantity plus the quantity that remains fresh make up the total production per acre per year. Prices are representative of the value of the fruit when it leaves the packing house door. All yield and price information is reported using 75-pound cartons.

Costs associated with the presence of HLB in the optimistic approach are derived from related studies (Brlansky et al., 2011; Irey et al., 2008; Morris and Muraro, 2008; Morris et al., 2009; National Research Council, 2011; O'Connell, 2009). The total increase in cost per acre (AC_t) is dependent upon the annual rate of spread of HLB (R_t). The higher the rate, the more trees that will need to be removed, increasing the costs proportionately for tree removal and replacement. The costs for controlling ACP populations (SP) and the costs for scouting (SC) were derived from studies on Florida's citrus industry (Brlansky et al., 2011; Irey et al., 2008; Morris and Muraro, 2008; Morris et al., 2009; National Research Council, 2011) and California's citrus industry (O'Connell, 2009) and are assumed to be incurred immediately upon a detection of HLB throughout the state. The immediate costs (FC_t) are related to scouting (*SC*) and increase insecticide application (*SP*) and will take place regardless of the rate of spread of HLB.

Scouting costs (*SC*) are adjusted from the costs in Florida using purchasing power parity (PPP) to account for the difference in labor costs between Florida and California. This adjustment is made by evaluating the differences in minimum wage between the two states. The PPP adjustments are made to the cost of scouting from studies related to the costs of managing groves with HLB from studies conducted by Morris et al. (2008), Morris and Muraro (2008) and Irey et al. (2008). Increased insecticide application costs from these studies, in addition to values from studies conducted by Brlansky et al. (2011) and O'Connell et al. (2009) are used to estimate the cost of attempting to control ACP populations (*SP*). Tree removal (*RT*) and replacement costs (*PT*) are also derived from O'Connell et al. (2009) and Irey et al. (2008). Table 3.5 summarizes the annual costs associated with attempting to limit the spread of HLB used in the optimistic approach.

Chapter 4

RESULTS AND DISCUSSION

This study estimates the potential economic impact of huanglongbing (HLB) on the California orange industry. This economic impact is measured as the loss in production value and any additional production costs incurred by operating under the presence of HLB. Both the loss in production value and the additional production costs are simulated under a pessimistic, or do-nothing approach and an optimistic, or do-something approach. Each simulation consists of 10,000 iterations and are independent of one another. An assessment over 20 years after a hypothetical introduction of HLB for each approach is made.

Under both approaches it is assumed that the Asian citrus psyllid (ACP) has spread through the state, allowing HLB to spread upon arrival. In addition, it is assumed that all orange growers in the state act in the same manner as identified under each approach. The pessimistic, or do-nothing approach, assumes that growers do not modify their cultural practices upon detection of HLB, or at any point thereafter. The optimistic, or do-something approach assumes that immediate actions are taken in an attempt to limit the spread of HLB.

Pessimistic Approach Results

The value of the total loss in production estimated using the pessimistic approach can be considered an estimate of the total damage caused by HLB if no mitigation measures are taken. This total damage is measured as the loss in production value over time. The estimated loss in production value is avoidable by keeping HLB out of California over the next 20 years. The estimated loss in production is a result of HLB spreading through California’s 180,000 acres of oranges.

This study estimates the total damage caused by HLB under the pessimistic approach. The value of the loss in production increases over time, as HLB spreads and the relative yield (RY_t) decreases. The cummulative loss in production value in California due to HLB under a do-nothing approach over 20 years after initial sypmtom expression is estimated to be $2.7 billion, which is about $14,938 per acre. This estimated loss in production amounts to a 33% loss in production value when compared to the estimated average value of healthy production over a 20 year period.

Assuming the loss in production value is normally distributed, at a 5% significance level, it is estimated that the cummulative loss in production value could fall between $1.8 billion and $3.6 billion, which is between $9,905 and $19,971 per acre. The discount rate used to compute the present value of the losses in production values over 20 years is 3% (see Equation 3.11). Figure 4.1 depicts a histogram of the cummulative losses in production values that were obtained from the simulation analysis over the 20-year period.

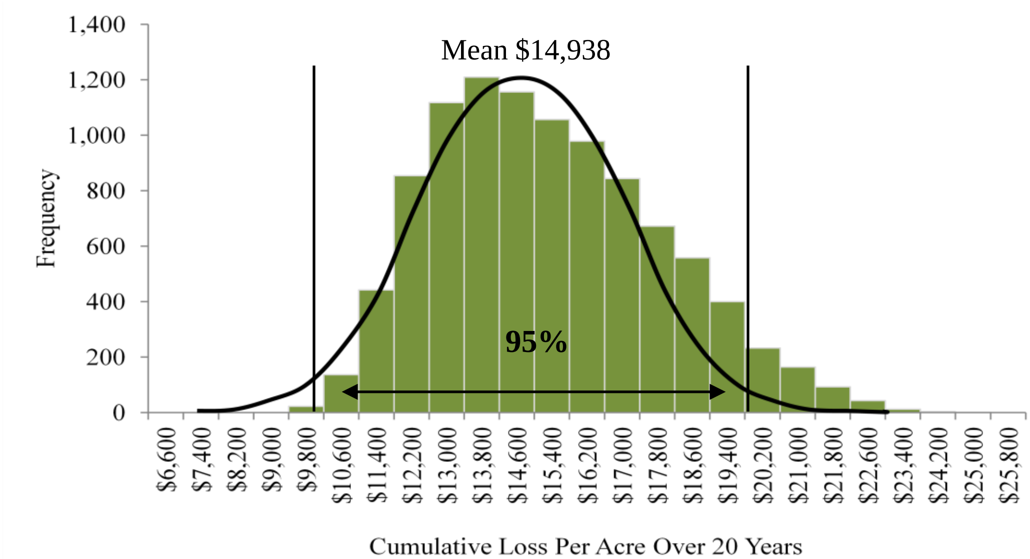

Figure 4.1. Histogram of the Estimated Per Acre Loss in Production Value Under the Pessimistic Approach

The production value over the last 20 years (1992-2011) has a value today of $14.5 billion (USDA, 1994; 1995; 1996; 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g).[10] This production value is computed with the number of bearing acreage changing every year. The estimated pessimistic loss in production value over 20 years represents a 19% reduction in value when compared to the last 20 years. If orange acreage was held constant at 180,000 bearing acres over the last 20 years (as it is assumed over the simulated 20 years), production value would have a value today of $10.2 billion. Compared to the latter production value, the estimated loss in production value under the pessimistic approach represents a 26% reduction over the next 20 years.

[10] Today's production value over the last 20 years is calculated using $FV=PV(1+i)^t$, where *FV* is future value, *PV* is the present value, *i* is the interest rate, and *t* is years. A 3% interest rate was used. This allows for a comparison with the estimated loss of production, which is calculated to the present value. This makes both values (past and projected) to be in 2012 dollars.

The average loss in production value per acre increases over time as disease severity increases and production decreases. The largest changes in production loss are seen in years 7 through 13 (refer to the fourth column in Table 4.1). This time frame is when HLB is expected to be spreading at the quickest rate, thus the greater increase in production value loss is realized.

Table 4.1. Present Value of the Estimated Average Loss in Production Value Per Year Under Pessimistic Approach

Year	Present Value Average Total Loss	Present Value Average Per Acre Loss	Present Value Change in Average Per Acre Loss
1	$57,393	$0.32	$0.32
2	$391,829	$2.18	$1.86
3	$1,668,250	$9.27	$7.09
4	$5,176,263	$28.76	$19.49
5	$12,771,238	$70.95	$42.19
6	$26,397,512	$146.65	$75.70
7	$47,318,240	$262.88	$116.23
8	$74,797,637	$415.54	$152.66
9	$106,670,665	$592.61	$177.07
10	$139,084,332	$772.69	$180.08
11	$169,734,903	$942.97	$170.28
12	$195,510,879	$1,086.17	$143.20
13	$215,215,448	$1,195.64	$109.47
14	$230,428,132	$1,280.16	$84.51
15	$239,235,826	$1,329.09	$48.93
16	$245,108,219	$1,361.71	$32.62
17	$246,917,161	$1,371.76	$10.05
18	$246,334,623	$1,368.53	($3.24)
19	$244,520,165	$1,358.45	($10.08)
20	$241,485,477	$1,341.59	($16.86)
Cumulative	$2,688,824,190	$14,937.91	-

Note: Present values were computed using a 3% discount rate.

Healthy Orange Yields

Healthy orange yields for each year were generated assuming a uniform distribution. Variations in yields were simulated 10,000 times for each of the 20 years that were projected. Since the values included in the uniform distributions for each year are the same, combined with the large number of iterations, the mean values for each year's healthy yields are similar (Figure 4.2). A range of 1.16 cartons per acre was obtained over the 20 years of estimated healthy yields (Figure 4.2). Due to the average age of the orange trees in California (Figure 3.6), annual production of healthy trees should be relatively stable. Annual healthy yields are randomly generated from uniform distributions with specific boundaries, as production per acre in the past 10 years has fallen between 242 and 354 cartons per acre (see horizontal red lines in Figure 4.2) (USDA, 2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g). Figure 4.2 illustrates the past average orange yield per acre and the simulated average projected yield per acre. The red horizontal lines represent the minimum and maximum values assumed in the uniform for the expected healthy yield.

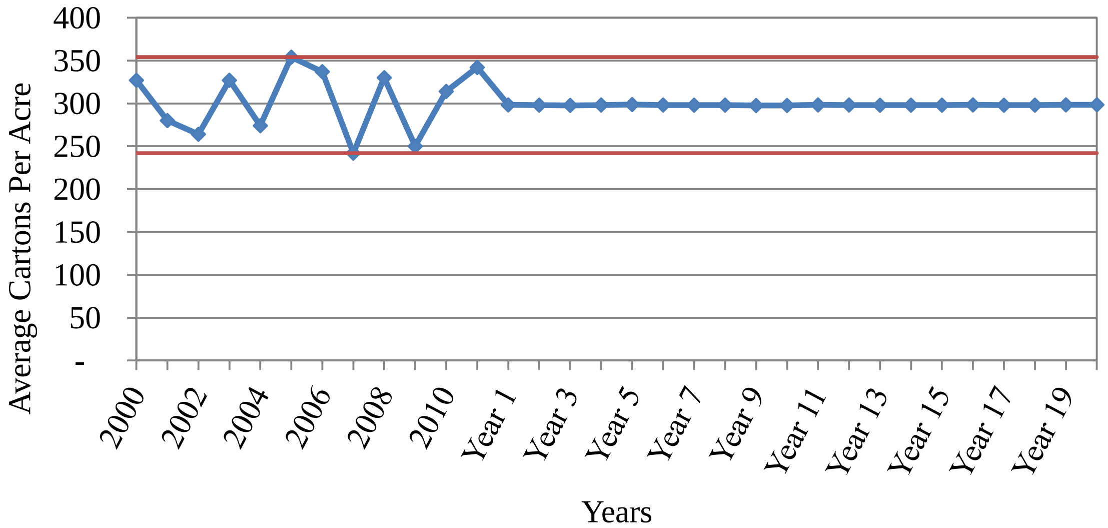

Figure 4.2. Past Average Annual Orange Yield Per Acre and Simulated Average Estimated Healthy Yield Per Acre

Source: USDA (2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g). Computed by Author.

For each iteration included in the simulation the estimated healthy yield is selected from a range of values for each year, which is not equal to the mean. This means that the combined estimated healthy yield over 20 years varies within each iteration. This can be made clearer by looking at the total estimated yield over the 20 year period. The average of the total estimated cartons per acre over 20 years is 5,961 75-pound cartons (see Figure 4.3). Assuming healthy yields are normally distributed, at a 5% significance level, it is estimated that total healthy production per acre over 20 years will fall between 5,677 and 6,246 cartons.

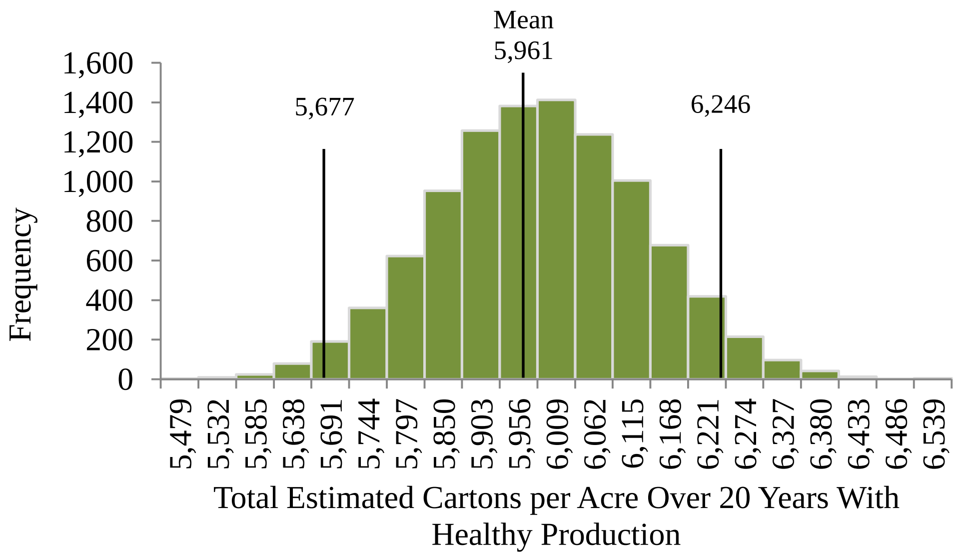

Figure 4.3. Histogram of Estimated Healthy Yield of Orange Production Per Acre Over 20 Years Under the Pessimistic Approach

Relative Orange Yield

The relative yield (RY_t) is the proportion of estimated healthy yields that still are produced under the presence of HLB. The relative yield decreases as HLB spreads over time and is dependent upon the disease severity of the previous year. As the relative yield decreases, the percentage of the estimated healthy yield that is lost to HLB increases. This means that the higher the relative yield, the lower the expected yield loss under HLB (see Equation 3.5). This can be seen in Figure 4.4.

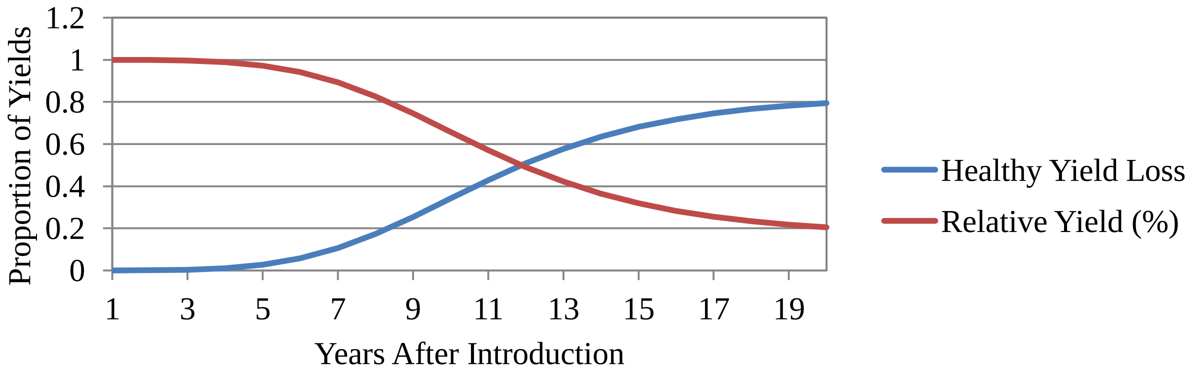

Figure 4.4. Simulated Relative Yield and Healthy Yield Loss Under the Pessimistic Approach

The relative yield for each year (derived from Equation 3.4) is dependent upon the values used for the proportion of HLB symptom expression in individual tress (s_o), the annual rate of HLB spread in individual trees (r), and the annual rate of HLB incidence progress (R). The averages for these parameters obtained from the simulation analysis are summarized in Table 4.2. The relative yield is calculated for each individual year using Equation 3.4 and will never be larger than any of the prior years under the pessimistic approach. For each of the 20 years included in the simulation, an average value can be derived for each individual distribution for each relative yield (refer to the second column in Table 4.3). The mean relative yield decreases over time as HLB spreads. Until year 10, the relative yield increases at an increasing rate, after which it increases at a decreasing rate (refer to the third column in Table 4.3).

Table 4.2. Mean, Minimum, Maximum and Standard Deviation of s_o, r, and R Under the Pessimistic Approach

Summary Statistics Included in the Pessimistic Approach				
Parameter	Mean	Standard Deviation	Minimum	Maximum
s_o	0.046	0.013	0.025	0.093
r	0.882	0.163	0.690	1.575
R	0.300	0.059	0.230	0.609

Table 4.3. Mean, Minimum, Maximum and Standard Deviation of Simulated Relative Yields Under the Pessimistic Approach

Relative Yield (%)					
Year	Mean	Difference From Year Prior	Minimum	Maximum	Std. Deviation
1	0.9999	-	0.9993	1.0000	0.0001
2	0.9992	0.0007	0.9928	0.9998	0.0006
3	0.9967	0.0026	0.9694	0.9993	0.0027
4	0.9894	0.0073	0.9142	0.9979	0.0084
5	0.9730	0.0163	0.8006	0.9947	0.0200
6	0.9425	0.0305	0.6474	0.9879	0.0391
7	0.8940	0.0486	0.4954	0.9754	0.0639
8	0.8270	0.0669	0.3761	0.9543	0.0896
9	0.7459	0.0811	0.2950	0.9215	0.1102
10	0.6580	0.0879	0.2439	0.8753	0.1216
11	0.5710	0.0870	0.2127	0.8162	0.1230
12	0.4911	0.0799	0.1938	0.7469	0.1161
13	0.4219	0.0692	0.1825	0.6716	0.1040
14	0.3646	0.0573	0.1756	0.5955	0.0896
15	0.3186	0.0460	0.1715	0.5234	0.0750
16	0.2826	0.0361	0.1690	0.4586	0.0615
17	0.2547	0.0279	0.1675	0.4026	0.0499
18	0.2334	0.0213	0.1666	0.3556	0.0401
19	0.2172	0.0162	0.1660	0.3170	0.0320
20	0.2048	0.0123	0.1657	0.2858	0.0255
Minimum	0.2048	0.0007	0.1657	0.2858	0.0001
Maximum	0.9999	0.0879	0.9993	1.0000	0.1230
Range	0.7951	0.0873	0.8336	0.7142	0.1229

HLB Orange Yields

The average values for the estimated healthy yields (HY_t) and the expected yields under the presence of HLB (EY_t) for each year can be estimated and are shown in Figure 4.5. As illustrates in Figure 4.5, the estimated healthy yield line is relatively flat since the same uniform distribution is used for each year (see Figure 4.2). The vertical black lines represent the estimated average loss in production due to the presence of HLB. Decreases in yields as a result of HLB infection will be noticed by individual growers earlier on, although the industry as a whole are estimated to start seeing a noticeable decline in production around year 5 (approximately 1.4 million 75-pound cartons, Figure 4.5). This extended time between initial infection and increased yield loss is related to the fact that the average tree age in California is 10 years or older. The older the trees, the slower the spread. The estimated cumulative loss of the average values over 20 years is approximately 408.5 million 75-pound cartons.

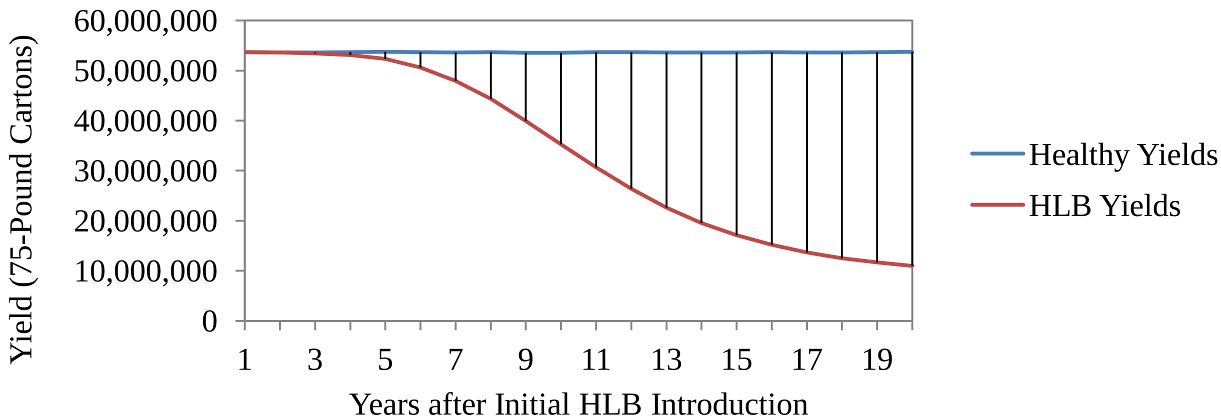

Figure 4.5. Average of Simulated Total Orange Yields for the State of California Under the Pessimistic Approach

Expected yields under the presence of HLB are dependent upon the relative yield. This means that the rate of increased loss in production increases at an increasing rate until year 10, then continues to increase at a decreasing rate (refer to the third column in Table 4.4). Table 4.4 summarizes the simulated values for the estimated yields under an HLB endemic. After 11 years post an HLB introduction in the state, production is estimated to be decreased by over 50% (Table 4.4).

Table 4.4. Mean, Minimum, Maximum and Standard Deviation of Simulated HLB Yields Per Acre Under the Pessimistic Approach in 75-Pound Cartons

Year	Mean	Difference From Year Prior	Minimum	Maximum	Std. Deviation
1	298.21	-	242.02	353.97	32.21
2	297.73	0.49	241.25	353.90	32.40
3	296.76	0.97	238.64	353.71	32.32
4	294.98	1.78	226.17	352.93	32.11
5	290.65	4.32	203.07	351.48	32.14
6	281.03	9.62	181.79	347.57	32.88
7	266.41	14.62	143.48	343.43	35.07
8	246.50	19.91	98.41	335.21	38.00
9	221.94	24.56	78.42	323.08	40.64
10	195.83	26.11	65.12	304.75	42.16
11	170.31	25.52	56.26	284.19	41.37
12	146.42	23.89	51.71	259.17	38.21
13	125.68	20.73	47.39	231.59	33.95
14	108.65	17.04	43.73	207.18	29.31
15	94.90	13.75	43.33	176.00	24.54
16	84.28	10.62	41.56	154.74	20.62
17	75.90	8.38	40.89	135.12	17.12
18	69.54	6.36	40.93	122.74	14.07
19	64.78	4.76	40.44	108.41	11.82
20	61.11	3.67	40.28	101.12	10.05
Minimum	61.11	0.49	40.28	101.12	10.05
Maximum	298.21	26.11	242.02	353.97	42.16
Range	237.10	25.62	201.75	252.85	32.11

Fresh and Processed Orange Prices

The prices for both fresh and processed oranges were included in the simulation assuming normal distributions. Prices for fresh oranges average $12.74 per carton, with a standard deviation of $1.17, while the processed orange prices average $0.76 per carton, with a standard deviation of $0.25. The prices for each of the 20 years are independent of one another and each have their own individual distributions, although the mean and standard deviation are identical (see Table 4.5).

Table 4.5. Mean, Minimum, Maximum, and Standard Deviation of Estimated Fresh and Processed Orange Prices Under the Pessimistic Approach

Year	Average Fresh Price	Minimum Fresh Price	Maximum Fresh Price	Std. Deviation Fresh Price	Average Processed Price	Minimum Processed Price	Maximum Processed Price	Std. Deviation of Processed Price
1	12.75	7.96	17.06	1.16	0.76	-0.32	1.80	0.25
2	12.73	7.67	16.85	1.16	0.76	-0.17	1.85	0.25
3	12.73	8.39	17.02	1.15	0.76	-0.30	1.66	0.25
4	12.73	8.47	17.24	1.15	0.76	-0.26	1.69	0.25
5	12.73	8.31	17.76	1.16	0.76	-0.11	1.78	0.24
6	12.75	8.49	16.85	1.17	0.76	-0.17	1.79	0.25
7	12.74	8.24	17.40	1.15	0.76	-0.10	1.74	0.25
8	12.72	8.23	17.28	1.15	0.76	-0.16	1.84	0.25
9	12.74	8.32	17.08	1.15	0.76	-0.23	1.78	0.25
10	12.74	8.31	17.12	1.16	0.76	-0.18	1.77	0.25
11	12.72	8.21	17.18	1.16	0.76	-0.37	1.76	0.25
12	12.72	8.42	17.51	1.15	0.76	-0.12	1.81	0.25
13	12.73	8.64	16.62	1.16	0.76	-0.18	1.60	0.25
14	12.74	8.66	17.37	1.15	0.76	-0.20	1.66	0.25
15	12.72	8.04	17.05	1.15	0.76	-0.17	1.73	0.25
16	12.73	8.09	17.28	1.16	0.76	-0.29	1.73	0.25
17	12.74	8.63	16.87	1.17	0.76	-0.23	1.71	0.25
18	12.72	8.44	16.88	1.16	0.76	-0.15	1.69	0.25
19	12.72	8.03	17.27	1.17	0.76	-0.22	1.72	0.25
20	12.73	8.35	17.33	1.16	0.76	-0.18	1.70	0.25
Minimum	12.72	7.67	16.62	1.15	0.76	-0.37	1.60	0.24
Maximum	12.75	8.66	17.76	1.17	0.76	-0.10	1.85	0.25
Range	0.03	0.99	1.14	0.03	0.01	0.27	0.26	0.01

Net Present Value of the Loss in Production

When the total value of the loss in production is adjusted using the present value, the discount rate used can create a large disparity within the final total value estimated for the loss over 20 years. Figure 4.6 depicts the effects of different discount rates used by displaying the annual average of the avoidable loss using a 3%, a 5%, and an 8% discount rate. By increasing the discount rate, the expected benefit of keeping HLB out of California decreases. The average estimated damage in year 20 is $241 million when using a discount rate of 3%, while if this rate is increased to 8%, the average loss in production value falls to just under $100 million. This shows the sensitivity of changing the discount rate. A change of 5% (3% to 8%) causes the average estimated loss for year 20 to decrease by just under $150 million.

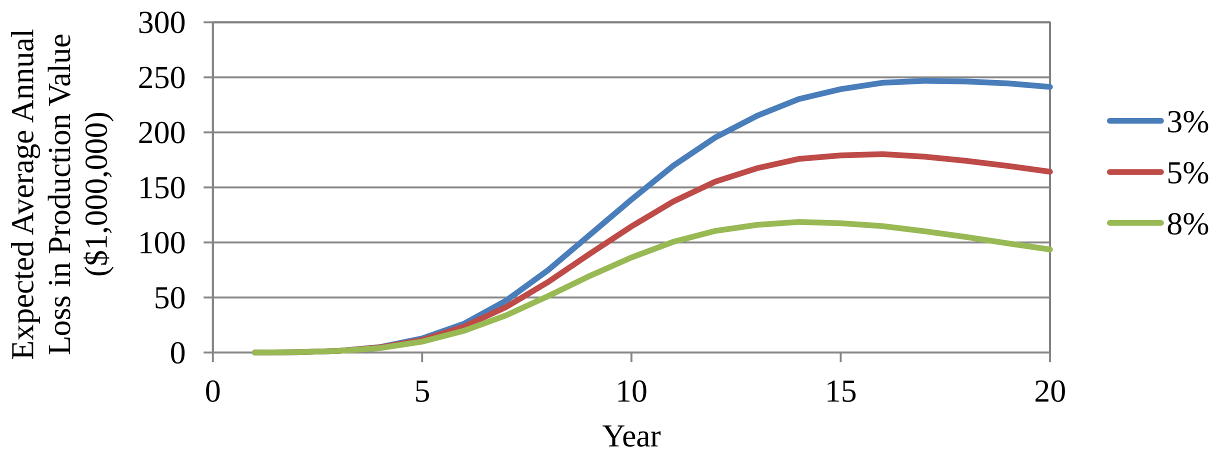

Figure 4.6. Discount Rate Sensitivity of the Pessimistic Approach

Optimistic Approach Results

In simulating an estimated value for the total damage caused by HLB under the optimistic approach, it is assumed that all growers take aggressive action in attempting to limit its spread.

This entails identifying diseased trees, removing them, replanting with disease free trees, and attempting to control ACP populations through additional pesticide applications. It is assumed that 180,000 acres are kept in production throughout the state over the course of 20 years. Total additional costs per acre are dependent upon the rate of spread of HLB.

While total production over 20 years is higher in the optimistic approach than in the pessimistic approach, the increases in costs to maintain production under the optimistic approach add to the increase in total damage caused by HLB. The total estimated damage in California due to HLB under the optimistic approach over 20 years after initial symptom expression is approximately $2.2 billion. This estimated total damage amounts to a 27% loss in value when compared to the estimated average value of healthy production. Assuming the total damage value is normally distributed, at a 5% significance level it is estimated that the total damage caused by HLB could fall between $2.1 billion and $2.3 billion. This can be broken down to $12,135 per acre, with a range that could fall between $11,469 and $12,800 (see Figure 4.7). The discount rate used to compute the present value of the total damage over 20 years is 3% (see Equation 3.23).

When compared to today's value of total orange production over the past 20 years (1992-2011) of $14.5 billion, the estimated optimistic total damages over the next 20 years represents a 15% reduction (USDA, 1994; 1995; 1996; 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g).[11] If orange acreage was held constant at 180,000 bearing acres over the last 20 years (as is assumed over the 20 year simulation) production value would have a value of $10.2 billion today (USDA, 1994; 1995; 1996; 1997;

[11] Today's production value over the last 20 years is calculated using $FV=PV(1+i)^t$, where FV is future value, PV is the present value, i is the interest rate, and t is years. A 3% interest rate was used. This allows for a comparison with the estimated loss of production, which is calculated to the present value. This makes both values (past and projected) to be in 2012 dollars.

1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006a; 2007a; 2008a; 2009; 2010a; 2011g). The estimated total damage represents a 21.4% decrease in value over the next 20 years when compared to the $10.2 billion.

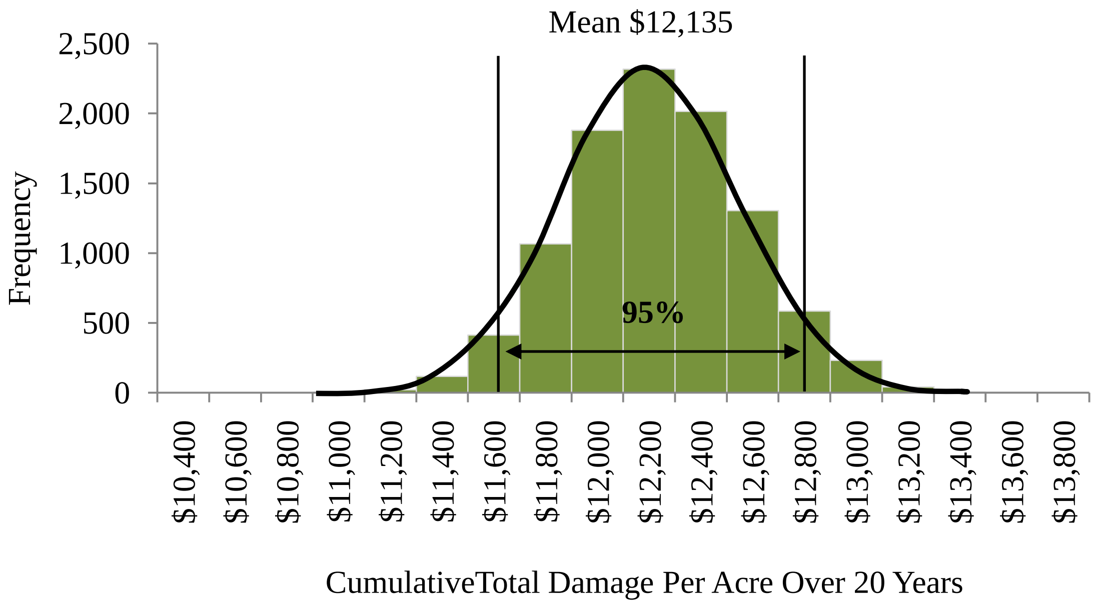

Figure 4.7. Histogram of the Estimated Per Acre Total Damage Under the Optimistic Approach

If cultural practices are modified, it is possible to maintain a healthy production level even under the presence of HLB. Total damage caused by HLB can be estimated by combining the total loss in production value with the total cost in mitigation (see Equation 3.12). The largest changes in total damages are incurred in years 1 through 6 (refer to the fifth column in Table 4.6). During this time period total yield loss per acre is increasing because the replacement trees have yet to come into production.

Table 4.6. Present Value of the Estimated Average Damage Per Year Under the Optimistic Approach

Year	Average Total Damages	Average Per Acre Total Damage	Average Per Acre Production Loss	Change in Average Total Damage
1	$90,888,843.95	$504.94	$59.37	$90,888,843.95
2	$107,374,957.36	$596.53	$115.75	$16,486,113.41
3	$114,303,185.22	$635.02	$168.24	$6,928,227.86
4	$120,648,000.90	$670.27	$217.28	$6,344,815.69
5	$126,665,980.78	$703.70	$263.95	$6,017,979.88
6	$132,199,811.49	$734.44	$307.33	$5,533,830.71
7	$128,456,243.06	$713.65	$299.04	$3,743,568.42
8	$124,567,816.26	$692.04	$289.45	$3,888,426.81
9	$120,870,771.76	$671.50	$280.72	$3,697,044.50
10	$117,230,066.32	$651.28	$272.04	$3,640,705.43
11	$113,853,218.19	$632.52	$264.38	$3,376,848.14
12	$110,650,806.23	$614.73	$257.11	$3,202,411.95
13	$107,456,123.68	$596.98	$249.75	$3,194,682.55
14	$104,281,166.51	$579.34	$242.28	$3,174,957.17
15	$101,238,507.84	$562.44	$235.19	$3,042,658.67
16	$98,283,472.98	$546.02	$228.38	$2,955,034.86
17	$95,408,519.31	$530.05	$221.65	$2,874,953.66
18	$92,716,223.22	$515.09	$215.56	$2,692,296.09
19	$89,890,501.91	$499.39	$208.66	$2,825,721.32
20	$87,250,118.50	$484.72	$202.45	$2,640,383.41
Cumulative	$2,184,234,335.46	$12,134.64	$4,598.57	-

Note: All values adjusted to present value using a 3% discount rate.

Healthy Orange Yields

Healthy yields for each year were generated assuming a uniform distribution, just as in the pessimistic approach. Since the same minimum and maximum values were used in both the pessimistic and optimistic approach, the annual estimated averages derived through simulation are similar in both approaches (see Table 4.7). This is evident when comparing the average total estimated number of cartons per acre over the 20 years. This is expected since the same uniform distribution was assumed under both approaches.

Table 4.7. Comparison of the Mean and Standard Deviation of the Optimistic and Pessimistic Approaches Annual Healthy Yields

Estimated Healthy Yields (75-Pound Cartons)				
	Optimistic Approach		Pessimistic Approach	
Year	Mean	Std. Deviation	Mean	Std. Deviation
1	297.91	32.12	298.25	32.21
2	298.44	32.18	297.95	32.43
3	298.23	32.23	297.75	32.39
4	298.17	32.43	298.15	32.34
5	298.21	32.37	298.72	32.46
6	298.20	32.49	298.16	32.54
7	297.86	32.37	297.97	32.52
8	298.09	32.56	298.07	32.50
9	297.71	32.22	297.55	31.98
10	297.78	32.28	297.64	32.31
11	298.31	32.27	298.25	32.39
12	297.83	32.33	298.16	32.43
13	298.51	32.38	297.87	32.17
14	298.21	32.50	297.97	32.62
15	298.37	32.13	297.97	32.41
16	298.01	32.31	298.25	32.54
17	298.20	32.48	297.91	32.27
18	298.26	32.45	298.01	32.37
19	298.04	32.67	298.32	32.27
20	297.72	32.33	298.42	32.53
Minimum	297.709	32.123	297.554	31.979
Maximum	298.515	32.672	298.716	32.619
Range	0.806	0.549	1.162	0.640

Under the optimistic approach the average total estimated cartons per acre over the 20 years is 5,962 75-pound cartons, while under the pessimistic approach it is 5,961 75-pound cartons. Using a 95% confidence interval, assuming a normal distribution, it is estimated that the total yield of healthy trees falls between 5,676 and 6,248 cartons over the 20 years included in the optimistic approach (see Figure 4.8). This is in comparison to the pessimistic approach with a 95% confidence interval range of 5,677 to 6,246 cartons per acre over the 20 years included in the simulation. This similarity is expected, as the same uniform distribution was assumed in each approach. This healthy yield estimation is the average value of the healthy yield used in Equation 3.22 to calculate the total yield per acre in year *t* post HLB.

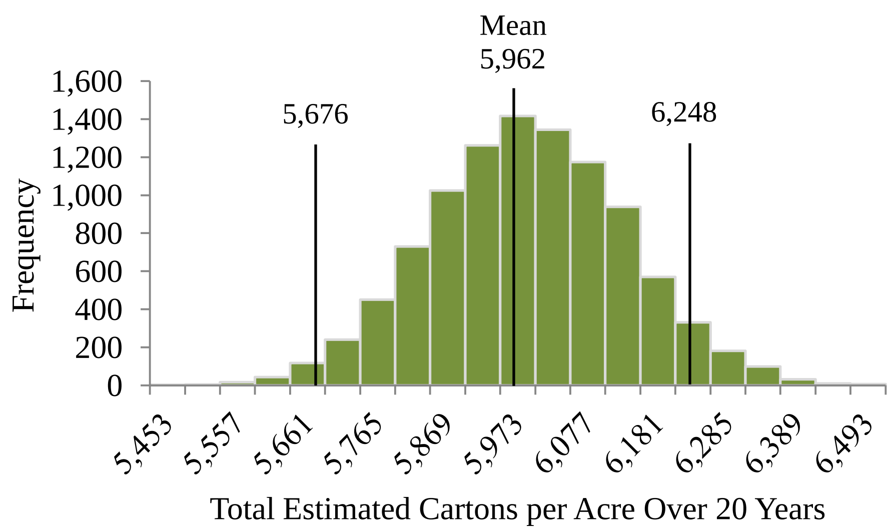

Figure 4.8. Histogram of the Total Estimated Cartons Per Acre Over 20 Years Under the Optimistic Approach

HLB Spread Rate

The rate of spread of HLB (R_t) is estimated assuming a PERT distribution.[12] The values used for the minimum, most likely, and maximum rates of spread used in the optimistic approaches

[12] PERT distributions are addressed in Appendix A.

simulation are 0.01, 0.02, and 0.03, respectively. Once trees are identified as being symptomatic they are removed. Therefore, when applying the rate of spread to a grove of trees, the value obtained is rounded, as only whole trees can be removed and not a fraction of a tree. This is not the case in the pessimistic approach, as trees are not removed and symptom expression can be isolated to specific portions of the tree canopy.

To account for the variation in HLB spread from year to year, each of the 20 years included in the simulation have their own PERT distribution. Over the 20 years, each of the distributions for the rate of spread will have similar average values. While this is the case, the total cumulative loss in trees per acre over the 20 years can be monitored in the simulation to see the actual implications of the rate of spread. Table 4.8 summarizes the simulation data for estimated tree removal due to HLB over the 20 years included in the simulation. The frequency with which the number of trees that are removed per acre is related to the rate of spread of HLB. More commonly 2 and 3 trees were lost per acre on an annual basis (see Table 4.8). Under the optimistic approach an average loss of 40% of the trees per acre as a result of HLB after 20 years is estimated. A range of 33% to 48% was obtained.

Table 4.8. Average Estimated Number of Trees Removed Per Year Due to HLB Under the Optimistic Approach

	Frequency of the Number of Removed Trees Per Acre				
Year	1 Tree	2 Trees	3 Trees	4 Trees	Average
1	124	5433	4425	18	2.4
2	137	5398	4442	23	2.4
3	133	5423	4431	13	2.4
4	143	5516	4330	11	2.4
5	125	5418	4437	20	2.4
6	127	5485	4372	16	2.4
7	151	5381	4465	8	2.4
8	151	5411	4421	17	2.4
9	147	5447	4397	9	2.4
10	149	5554	4279	18	2.4
11	130	5487	4367	16	2.4
12	132	5429	4427	12	2.4
13	137	5468	4381	14	2.4
14	106	5522	4356	16	2.4
15	148	5447	4396	9	2.4
16	133	5544	4312	11	2.4
17	134	5428	4419	19	2.4
18	149	5442	4393	16	2.4
19	143	5482	4354	21	2.4
20	143	5431	4414	12	2.4

HLB Orange Yields

Yield losses from HLB under the optimistic approach are dependent upon the rate of spread of HLB (R_t). All trees that are identified through scouting as being symptomatic are removed. The yield loss from a removed tree is assumed to be felt over a period of 6 years (see Equation 3.22). A replacement tree is planted the year after removal. It then takes the replacement tree 4 years to be considered as productive, although production at this point will be low.

Due to the length of time until production is regained from removed trees, losses in yields increase in the first 5 years after the initial detection of HLB. In year 6, when the replacement trees that were planted as a result of diseased trees being removed in year 1 become productive, the overall loss in yields start to level off. This is seen in Figure 4.9 as the line representing HLB yield. From year 6 on, replacement trees planted 5 years prior start to become productive. This is the case throughout the remaining years. The estimated cumulative loss of the average value over 20 years is over 113 million 75-pound cartons.

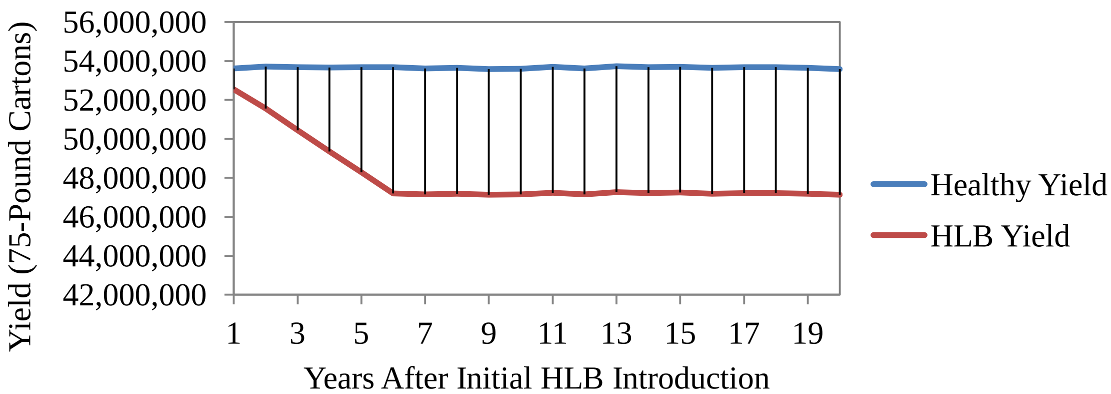

Figure 4.9. Estimated Average HLB Yields Per Acre Over Time

After year six, trees continue to be removed, while trees that were replaced in year 1 are coming into production. This creates a stable loss in yields. Table 4.9 shows the average estimated loss in yields over time. The loss in year 1 is estimated at 6 cartons per acre. The loss in year 2 is estimated at 12 cartons per acre. This is the loss generated from removing trees in year 1 and year 2, but is realized in year 2. Year 3 averages a loss of 18 cartons per acre. Once again, the loss incurred in year 3 includes the loss from the trees removed in year 1, 2, and 3, but is realized in year 3. This trend continues until the first replacement trees that were planted in year 2, that replaced the trees removed in year 1, come into production. From this point forward trees are both coming into production and leaving production.

Table 4.9. Estimated Loss Per Acre Under the Presence of HLB Under the Optimistic Approach

Loss in Production Per Acre Over Time		
Year	75-Pound Cartons Per Acre	Value Per Acre
1	6.0	$61.15
2	12.0	$122.79
3	18.0	$183.85
4	24.0	$244.55
5	30.0	$305.99
6	35.9	$366.97
7	35.9	$367.78
8	35.9	$366.66
9	35.9	$366.28
10	35.9	$365.59
11	35.9	$365.96
12	35.9	$366.58
13	35.9	$366.76
14	35.9	$366.47
15	35.9	$366.42
16	35.9	$366.49
17	35.9	$366.35
18	35.9	$366.97
19	35.9	$365.88
20	35.8	$365.65

Incurred Costs of Controlling ACP

There are two different types of costs incurred that are associated with attempting to limit the spread of HLB in the optimistic approach (see Equation 3.21). The first type of costs are assumed to be incurred immediately upon the detection of HLB and are comprised of additional pesticide applications (*SP*) and scouting (*SC*). These amount to an estimated $426.47 per acre per year. The remaining costs are dependent upon the rate of spread of HLB, as they are the costs related to removing symptomatic trees (see Equation 3.18) and subsequently replacing them (see Equation 3.19). These costs amount to $34.34 per tree, although the total cost is not incurred in the same year, as removed trees are replaced the year after removal. The average estimated increase in production costs per acre over the 20 years is $507.31.

Net Present Value of Total Damages

Just as in the pessimistic approach, the discount rate used can create a large disparity within the final value estimated for the total damage over 20 years. Figure 4.10 illustrates the effects of different discount rates used by displaying the annual average of the avoidable damage using a 3%, a 5%, and an 8% discount rate. If the discount rate is increased, total damage over the 20 years will decrease. This is a result of the time value of money being taken into account. Before adjusting to the present value, a value of $2.98 billion over the 20 years is obtained. This value does not take into account the fact that if this money was in someone's possession today, they could potentially invest it and incur interest over the next 20 years. The difference in the total estimated damage caused by HLB under the optimistic approach when using an 8% discount rate, from the 3% discount rate that was used, comes to $782 million.

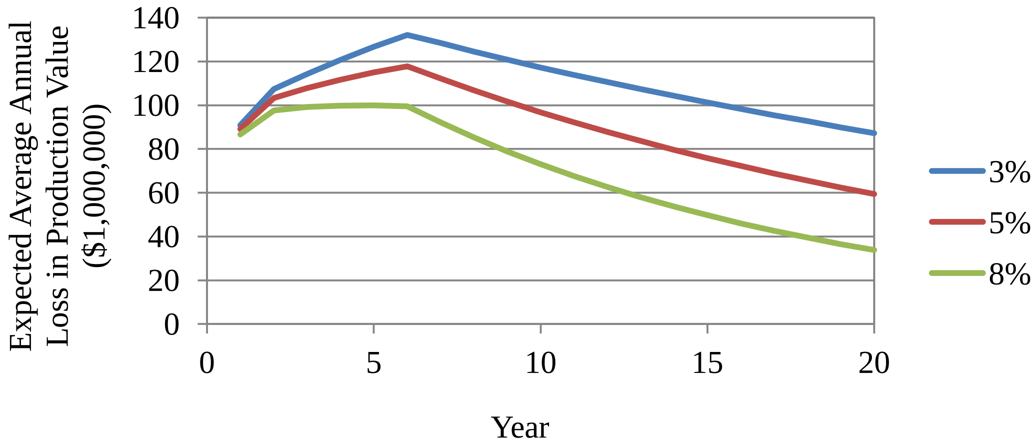

Figure 4.10. Discount Rate Sensitivity of the Optimistic Approach

Comparison of the Pessimistic and Optimistic Approach

Estimating the potential total damage of HLB on the California orange industry under different management approaches is beneficial to both growers and policy makers. These estimates can allow industry members, such as growers, an opportunity to determine the most economical approach to dealing with HLB. The simulations conducted under the pessimistic and optimistic approach consider the different implications with adopting the related management practices.

Under the pessimistic approach, the total damage caused by HLB is the total loss in production (see Equation 3.9), while under the optimistic approach the total damage is comprised of the loss in production in addition to the increase in production costs (see Equation 3.12). The pessimistic approach does not include any additional productions costs because it is assumed that growers do not change their cultural practices to attempt to limit the spread of HLB.

When comparing the loss in production value between the two approaches over a 20 year period, damages under the pessimistic approach are much higher. The total average annual damage under the pessimistic approach is $14,938 per acre, while under the optimistic approach it is $12,135. This is a difference of $2,803 per acre (see Table 4.10). Under the pessimistic approach it takes longer to see the reduction in yields. Under the optimistic approach yield loss is immediate and increases in production costs are realized right away as seen in Table 4.10.

Table 4.10. Comparison of the Average Total Damages and Differences in Average Production Losses Per Acre Under the Optimistic and Pessimistic Approaches

	Optimistic Approach			Pessimistic Approach	Difference	
Year	Average Total Damage	Average Increased Production Costs	Average Production Loss[1]	Average Total Damage[2]	Production Loss	Total Damage
1	$504.94	$445.57	$59.37	$0.32	$59.05	$504.62
2	$596.53	$480.78	$115.75	$2.18	$113.57	$594.35
3	$635.02	$466.77	$168.24	$9.27	$158.98	$625.75
4	$670.27	$452.99	$217.28	$28.76	$188.52	$641.51
5	$703.70	$439.75	$263.95	$70.95	$193.00	$632.75
6	$734.44	$427.11	$307.33	$146.65	$160.68	$587.79
7	$713.65	$414.61	$299.04	$262.88	$36.16	$450.77
8	$692.04	$402.59	$289.45	$415.54	$126.09	$276.50
9	$671.50	$390.78	$280.72	$592.61	$311.89	$78.89
10	$651.28	$379.24	$272.04	$772.69	$500.66	$121.41
11	$632.52	$368.14	$264.38	$942.97	$678.59	$310.45
12	$614.73	$357.62	$257.11	$1,086.17	$829.06	$471.44
13	$596.98	$347.23	$249.75	$1,195.64	$945.89	$598.66
14	$579.34	$337.06	$242.28	$1,280.16	$1,037.88	$700.82
15	$562.44	$327.24	$235.19	$1,329.09	$1,093.89	$766.65
16	$546.02	$317.64	$228.38	$1,361.71	$1,133.33	$815.69
17	$530.05	$308.40	$221.65	$1,371.76	$1,150.12	$841.71
18	$515.09	$299.53	$215.56	$1,368.53	$1,152.97	$853.44
19	$499.39	$290.73	$208.66	$1,358.45	$1,149.79	$859.05
20	$484.72	$282.27	$202.45	$1,341.59	$1,139.13	$856.86
Total	$12,134.64	$7,536.07	$4,598.57	$14,937.91	$12,159.24	$11,589.13

[1] Calculated using Equation 3.11.
[2] Calculated using Equation 3.23.

Discussion of Results Compared to Similar Studies

In Niemeyer et al.'s (2007) study examining the economic impact of HLB on the Texas citrus industry, an assessment of what impact a 20% and a 60% reduction in production value would have on the states citrus industry was made.[13] Niemeyer et al. (2007) assumed a 60% reduction in production value would be seen in 5 years after the introduction of HLB under a do-nothing approach, while under the pessimistic approach (also a do-nothing approach), it is estimated that a 60% reduction in production value would be seen after 12 years. Niemeyer et al.'s study only assumed a 60% reduction in production value after 5 years and did not model the rate of spread of HLB. While this is a difference of over 7 years of the estimated time to reach a reduction of 60% in production value, at the time the study was conducted, Texas had an estimated 27,300 bearing acres of citrus, while California had an estimated 267,000 bearing acres, with 180,000 strictly orange acreage (USDA, 2009). The large disparity in bearing citrus acreage may contribute to the possible difference in the amount of time it is estimated to take production value to decrease by 60%.

Niemeyer et al. (2007) estimated that 1,911 jobs are directly related to the citrus industry in Texas, while Wunderlich (2010) estimated 26,000 jobs are directly related to the citrus industry in California. Niemeyer et al. (2007) estimated a 56.5% reduction in jobs if HLB reduced production value by 60% after 5 years of introduction. Applying this estimate to the 26,000 jobs Wunderlich (2010) estimated to be directly related to the citrus industry in California, an estimated 14,690 jobs would be lost.

Salcedio et al. (2011) estimated the potential economic impact of HLB on the Mexican citrus industry.[14] It was determined that depending on the location in the country, the variety of

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[13] Niemeyer et al.'s 2007 study is discussed further in Chapter 2.
[14] Salcedio et al.'s 2011 study is discussed further in Chapter 2.

citrus, and the level of disease severity, the degree of fruit loss would change. When considering the entire country to be under an HLB endemic at the same time, Salcedio et al. (2011) estimate that a 14% loss in production would be seen the first year, a 24% loss in production after the third year, and a 38% loss in production after the fifth year. This amounts to a loss of $599.81 million in U.S. dollars in all varieties of citrus after 5 years. Under the pessimistic approach, it is estimated that after the fifth year post a detection of HLB in California, production would decrease by 6%, resulting in a $46.4 million loss in orange production alone. Under the optimistic approach, it is estimated that after the fifth year post a detection of HLB in California, production would decrease by 12%, resulting in a $203.7 million loss in orange production alone.

According to Salcedio et al. (2011), citrus yields in many regions of Mexico are lower that than those seen in other citrus producing countries. This may possibly be why production is estimated to decrease at a quicker rate in Mexico, than what is estimated to take place in California. It is important to note that Salcedio et al. (2011) is considering the loss in production value for all varieties of citrus in the entire country of Mexico, while the pessimistic and optimistic approach estimates only consider the loss in orange production value in the state of California.

The economic impact of HLB in Florida was examined by Hodges and Spreen (2012).[15] Only looking at the impact on processed citrus over a period of 5 years after the introduction of HLB, a 12% decrease in total revenues was estimated, when compared to a predicted revenue value of $11.06 billion if HLB were not present (Hodges and Spreen, 2012). This estimate is based off of mixed management practices. Some growers in Florida have not altered their production practices, some have abandoned their groves, and the remaining growers have

[15] Hodges and Spreen's 2012 study was discussed further in Chapter 2.

attempted to limit the impact of HLB using a variety of techniques, including, but not limited to foliar nutrition programs, removal of diseased trees, and increased attempts at controlling ACP populations. The total revenue in this case is based off of the return to the actual grower, while under the pessimistic and optimistic approach, the production value is based off of the packed product leaving the packing house. Hodges and Spreen (2012) estimated that a 23% reduction in production was a direct result of HLB at the end of 5 years after its introduction to the state. This can be compared to either the pessimistic or optimistic approaches estimates of a reduction in production of 6% and 12% respectively after 5 years of an initial infection.

In Salifu et al.'s (2012) study that also looked at the economic impact of HLB on the Florida citrus industry under a do-nothing approach, it was estimated that full grove infection would take place in a mature citrus grove around 20 years after the introduction of HLB.[16] This can be compared to the pessimistic approach, which is also a do-nothing approach. Under the pessimistic approach, it is estimated that near full grove infection of HLB would take place roughly 23 years after an HLB introduction. Different initial incidence rates were used in Salifu et al.'s (2012) study and the pessimistic approach, 0.10% and .01% respectively. The initial incidence rate influences the rate of spread of HLB throughout a grove. Another difference between these two studies is that Salifu et al. (2012) are analyzing a grove of trees that are assumed to be of the same age, while the pessimistic approach accounts for variability in tree age.

In actually providing an estimate for the potential economic impact of HLB under a do-nothing approach, Salifu et al. (2012) examined the total cost of production and not just the increase cost of production. Under the pessimistic and optimistic approach, only the increase in production costs caused by HLB are examined, and not the total production costs. Since the

[16] Salifu et al.'s 2012 study is discussed further in Chapter 2.

majority of the trees in California are 10 years or older, when comparing the same age bracket from Salifu et al.'s (2012) study, they estimate that revenues will exceed costs for up to 8 years after disease introduction. A negative net present value is obtained for any trees younger than 10 years old, regardless of the initial disease incidence rate (Salifu et al., 2012).

Bassanezi et al. (2011) examined yield loss caused by HLB in Brazil. A similar equation for relative yield (RY_t) was used as in Equation 3.4 under the pessimistic approach, although instead of -1.8 being multiplied by the total disease severity (TD_t), -1.85 was used. This is shown in

(4.1) $$RY_t = e^{(-1.85TD_t)}.$$

The -1.8 used under the pessimistic approach to calculate relative yield was modeled after research conducted by Bassanezi and Bassanezi (2008). A 14% to 19% relative yield was seen when disease severity reached 100% in Brazil (Bassanezi et al., 2011). The same relative yield was seen when disease severity reached 100%, when using Equation 3.4 (Bassanezi and Bassanezi, 2008).

Chapter 5

CONCLUSION AND IMPLICATIONS

With California contributing over 80% of the nation's fresh oranges, it is important to attempt to keep huanglongbing (HLB) from being introduced in the state. Quantifying the potential economic impact of HLB under different management approaches is essential in developing the most appropriate mitigation actions to take if HLB is discovered in California. In 2009 California contributed 45% of the United States citrus industry's nearly $2.9 billion production value (USDA, 2011g). As California's 15th ranked commodity in terms of production value, orange production was worth an estimated $722 million in 2010 (USDA, 2011f). Employing around 26,000 people in the state (Wunderlich, 2010), the citrus industry in California is worth protecting from the spread of diseases.

The main objective of this study was to approximate the total loss in the value of orange production in California under a pessimistic and an optimistic scenario. Two management strategies were presented, allowing for a comparison in the estimated total damage costs related to the presence of HLB. One scenario estimated the costs associated with a do-nothing approach, referred to as a pessimistic approach, while the second scenario included costs related to attempting to minimize the potential damage caused by HLB, and is referred to as an optimistic approach. Monte Carlo simulations were employed to estimate the total damage of HLB in California under both approaches.

Under the pessimistic approach, HLB is free to spread throughout the entire state with no attempts to stop it. The total loss in production value is estimated based on the dispersion rate of HLB though individual trees and through a block of trees. If HLB is allowed to spread throughout the state with no attempts to limit it, for a period of 20 years, today's total loss in production value, on average is estimated to be $2.7 billion. This estimated loss in production amounts to a 33% loss in production value when compared to the simulated average value of healthy production. When compared directly to today's value of the past 20 years of production, this is equivalent to an estimated 19% reduction in the present value over the next 20 years if HLB were to be detected in 2012. Under the pessimistic approach, the amount of orange acreage is held constant at 180,000 acres. If the amount of acreage was held constant at 180,000 over the past 20 years, as was done in the projected twenty years included in the simulation of the total loss under the pessimistic approach, an estimated 26% decrease in production value is estimated.

Under the optimistic approach, where growers take aggressive action attempting to limit the spread of HLB, today's total damages of HLB over the 20 year period considered is on average estimated to be $2.2 billion. This estimated total damage amounts to a 27% loss in value when compared to the simulated average value of healthy production. When compared directly to today's value of the past 20 years of production, this is equivalent to an estimated 15% reduction in the present value over the next 20 years if HLB were to be detected in 2012 is obtained. Under the optimistic approach, the amount of orange acreage is held constant at 180,000 acres. If the amount of acreage was held constant at 180,000 over the past 20 years, as was done in the projected twenty years included in the simulation of the total damage caused by HLB under the optimistic approach, an estimated 21% decrease in production value is estimated.

One of the objectives of this study was to assess the added cost of producing under the presence of HLB. The costs associated with attempting to limit the spread of HLB were identified under the optimistic approach. These costs pertained to scouting for HLB, removing trees infected with HLB, replacing removed trees with healthy nursery stock, and attempting to limit ACP populations. An increase in the fixed cost of production are estimated at $426.47 per acre per year, while the average variable costs of production are estimated at $80.84 per acre per year. This amounts to an average increase in production costs under the presence of HLB to be estimated at $507.31 per acre per year.

When comparing the loss in production value between the pessimistic and optimistic approaches over a 20 year period, damages under the pessimistic approach are much higher. The average total annual damages estimated under the pessimistic approach is $14,938 per acre, while under the optimistic approach it is $12,135 per acre. This is a difference of $2,803 per acre over the 20 years that are projected. Under the pessimistic approach it takes longer to see the reduction in yields. Under the optimistic approach yield loss is immediate and increases in production costs are realized right away. The difference in the yield loss is related to the fact that under the pessimistic approach, trees are left to continue to produce until they die, while under the optimistic approach, trees are removed immediately upon disease detection.

Under the optimistic approach, an increase in pesticide applications is assumed. Not only is this costly to growers, it is can be detrimental to the biological balance in the citrus groves. Pesticides do not discriminate against pests when applied. Not only are the target pest populations decreased, in this case ACP, but the beneficial insect populations are affected as well. The increased cost of production under the optimistic approach could possibly lead to a decrease in orange acreage kept in production, if HLB is detected in California. Although this may be the case, attempting to limit the spread of HLB is still considered to be an optimistic approach, as it is currently the only known method that can keep the citrus industry productive. Although production costs are increased, the total damage caused by HLB is significantly less under the optimistic approach than in the pessimistic approach. This is with an estimated just over a half a billion dollars saved in production value alone, over the 20 years included in the simulation of the total damage caused by HLB, when compared to the pessimistic approach.

Being able to keep orange production from declining to levels seen under the pessimistic approach is beneficial to the citrus industry. Under the pessimistic approach, production is estimated to be decreased by over 50% after 11 years following an HLB introduction. The loss of production is felt by more people than just the famers that grow the oranges. As production declines, packing houses do not run, box makers do not sell their product, shipping companies do not operate, etc. An issue arises with who is bearing the increased cost in production. Under the optimistic approach, the grower is absorbing the additional costs of production. This could potentially lead to less orange acreage being kept in production. Attempting to limit the spread of HLB is the superior choice when only considering the pessimistic and optimistic approaches, although alternative management options should be further explored. Not only is less money lost as a result of HLB, but the citrus industry in California may not survive if growers as a whole do not attempt to limit the spread of HLB immediately upon detection.

Limitations

Under both the pessimistic and optimistic approach it is assumed that the growers will act in the following fashion. Under the pessimistic approach, it is assumed that no growers modify their cultural practices in an attempt to limit the spread of HLB. Trees are left in the field until they are no longer productive and no new planting takes place. Under the optimistic approach it is assumed that all growers attempt to limit the spread of HLB. It is assumed that all growers identify diseased trees, remove them, and replace them with healthy trees. In this sense, these two approaches are opposite to each other and could be considered as two extremes. In reality, each grower will respond to the detection of HLB in California to different degrees, and will adjust their management practices as they deem necessary, or as required by modified regulations.

Under the optimistic approach, the modifications in cultural practices of neighboring growers in attempting, or not attempting, to limit the spread of HLB can have a direct impact on the rate of spread of HLB. If a grower is attempting to limit the spread and a neighboring grower is not, a constant source of ACP and HLB is present. This makes it more difficult to keep HLB at low levels in the groves attempting to be controlled. In some instances, citrus groves are abandoned (USDA, 2010), which allows for an uncontrollable source of inoculum.

This study assumes that the impact of HLB in California is going to be similar to the impact that it had in Florida. For example, under the optimistic approach it is assumed that the cost of replacement trees doubles. This follows what was seen in Florida after the detection of HLB. It is possible that the increase may not be as high, although it is very likely that there would be some sort of increase in the cost of replacement trees, as dictated by the laws of supply and demand. As the demand for nursery stock increases in response to a growing number of new plantings being needed to replace the removed disease trees, prices for nursery stock are expected to increase. Until producers are able to satisfy the demand, it is expected that costs for replacement trees will be higher than what they were prior to the detection of HLB. In Florida, as of 2010, five years after the initial detection of HLB in the state, the supply of nursery stock had yet to fulfill the demand for replacement trees (National Research Council, 2010).

Given the lack of available data, this study assumed the cost of scouting in California will be similar to the cost of scouting in Florida. Since HLB has not been discovered in California, the cost of scouting in California is unknown. Given that no data is available, the theory of purchasing power parity was used to estimate the cost of scouting in California. If HLB is ever found in California, accessibility and good record keeping of the costs of preventing the spread of the disease from becoming endemic would allow applied economists to better estimate the potential economic impact of HLB on the California citrus industry.

Suggestions for Future Research

While examining the potential economic impact on the orange industry is beneficial, oranges are only a segment of the citrus industry. Oranges make up 77.5% of the estimated bearing citrus acreage in the U.S. and 67.3% in the state of California (USDA,2011). This study focused on the orange industry due to the fact that biological parameters related to the spread of HLB in other types of citrus are not as widely available. These biological parameters include the annual incidence rate in individual trees and through a grove of trees. Expanding this research to look at implications to the entire citrus industry would be beneficial, as there are an estimated additional 90,000 bearing acres of other citrus varieties in the state (USDA, 2011).

The total potential damage caused by HLB under either approach can be looked at as the total avoidable cost if HLB is not introduced to California over the next 20 years. This means that the amount of money allocated to keeping HLB out of the state is beneficial up to the total estimated damage caused by the disease. A question between what is more desirable, prevention versus control arises. The possible risk associated with an HLB introduction can possibly be lessened by modifying regulations pertaining to possible routes of disease introduction. Exploring how regulations can minimize the risk of introduction is a topic that could be further researched. The probability of introduction could also be incorporated in either of the models considered in this study.

This study does not include the entire effect of what a loss in orange production could have on the economy as a whole. This study could be expanded by analyzing the impact the citrus industry could have on other industries if HLB becomes endemic in California. Large decreases in production, as seen under the pessimistic approach will likely affect other types of businesses than just growers and packers. A variety of businesses rely on a sustainable production of oranges to continue operating at the current capacity, or even operate at all. Some of these businesses include orange packing and processing companies, transportation companies, custom citrus harvesters, and marketing companies. Given the time and resource constraints, this study only estimates the likely implications of decreased production value and increase in production costs if HLB is introduced to the California orange industry and not this impact to the entire California economy.

In addition, a sensitivity analysis under the pessimistic and optimistic approach could be conducted to determine how variables of interest influence the estimated total damage caused by HLB. This analysis is similar to the sensitivity analysis that was conducted for the discount rate in Chapter 4. Everything else is held constant except for the variable being analyzed. This would potentially give light to determining how responsive the total damage is to changes in variables/parameters of interest. Some of the variables/parameters that may be checked for sensitivity are the percent processed (k_t), the annual rate of spread (R_t) the price of both fresh and processed oranges (p_{ft} and P_{pt} respectively), and increased costs in production which consist of the cost of tree removal and replacement, scouting costs, and additional spray costs (*CR*, *CP*, *SC*, *SP* respectively).

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APPENDICES

APPENDIX A

DISTRIBUTIONS

DISTRIBUTIONS

Three different distributions are used in both the pessimistic and optimistic approach in Chapter 3. These three distributions are the PERT distribution, the uniform distribution, and the normal distribution. Supplemental information regarding these distributions is included in this Appendix.

PERT Distribution

PERT is an acronym for Project Evaluation and Review Technique. The PERT distribution was originally developed to help estimate the time requirements for large planning projects as a risk assessment tool (Kamburowski, 1997). PERT distributions are comprised of a minimum value (*a*), a most likely value (*b*), and a maximum value (*c*). Often written PERT(*a*, *b*, *c*), the mean is a weighted average with the most likely value holding more weight than the minimum and maximum value. The mean of a PERT distribution is expressed as

(A.1) $$\mu = \frac{a+4b+c}{6}\,.$$

The standard deviation of the PERT distribution is one-sixth of the range between the minimum and the maximum values (Kamburowski, 1997). This means that the variance is

(A.2) $$\sigma^2 = \frac{(c-a)^2}{36}.$$

This distribution is a version of a Beta distribution where

(A.3) $$PERT(a,b,c) = Beta(\alpha_1,\alpha_2)(c-a)+a,$$

and

(A.4) $$\alpha_1 = \frac{(\mu-a)(2b-a-c)}{(b-\mu)(c-a)},$$

(A.5) $$\alpha_2 = \frac{\alpha_1(c-\mu)}{(\mu-a)},$$

and the mean is equal to Equation A.1. $Beta(\alpha_1, \alpha_2)$ is a density function which according to Castella and Berger (2001) is expressed as

(A.6) $$f(x|\alpha_1, \alpha_2) = \frac{1}{Beta(\alpha_1,\alpha_2)} x^{\alpha_1 - 1}(1 - x)^{\alpha_2 - 1},$$

where

(A.6) $$Beta(\alpha_1, \alpha_2) = \int_0^1 x^{\alpha_1 - 1}(1 - x)^{\alpha_2 - 1}\, dx.$$

Since its development, the PERT distribution has had a variety of applications, from modeling expert opinions (Vose, 2000) to modeling the spread of various pests and diseases (Cook et al., 2007; Cook and Mathenson, 2008; Waage et al., 2004). It is often incorporated into simulation studies (Cook et al., 2007; Cook and Mathenson, 2008). The use of a distribution in a simulation study allows for considering a range of possible values as opposed to only using a single value.

The shape of a PERT distribution can vary, depending on the most likely value used. If the most likely value is in the middle of the maximum and minimum values, the shape of the distribution looks similar to a normal distribution (Figure A.1, Panel B). If the most likely value is closer to minimum value or the maximum value, the shape of the distribution will be skewed right (Figure A.1, Panel A) or skewed left (Figure A.1, Panel C) respectively. Figure A.1 summarizes this for 10,000 iterations using the same minimum and maximum values in all three panels, but with different most likely values. While the minimum and maximum is the same for all three different distributions, the mean value (represented by a vertical black line in Figure A.1) varies depending upon the most likely value.

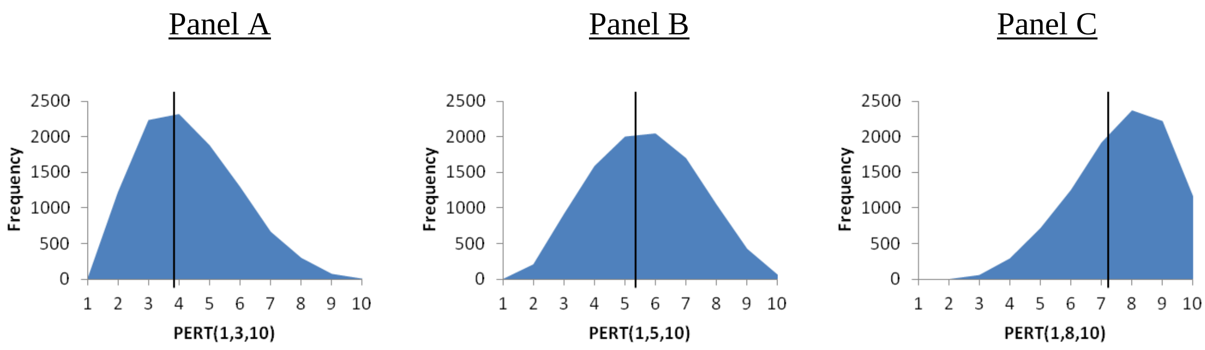

Figure A.1. Example of Different PERT Distributions

Uniform Distribution

Uniform distributions are defined by a minimum (*a*) and a maximum (*b*) value. Any value between these two numbers has an equal chance of being selected. As provided by

(A.7) $$f(x) = \frac{1}{B-A},$$

where $A \leq x \leq B$ (NIST/SEMATECH, 2012). The mean of the uniform distribution is expressed as

(A.8) $$\mu = \frac{a+b}{2}.$$

According to Wesstein (2012) the variance of the uniform distribution is expressed as

(A.9) $$\sigma^2 = \frac{(b-a)^2}{12}.$$

This means that the standard deviation of the uniform is

(A.10) $$\sigma = \sqrt{\frac{(b-a)^2}{12}}.$$

Figure A.2 illustrates a uniform distribution with *a*=242 and *b*=362.

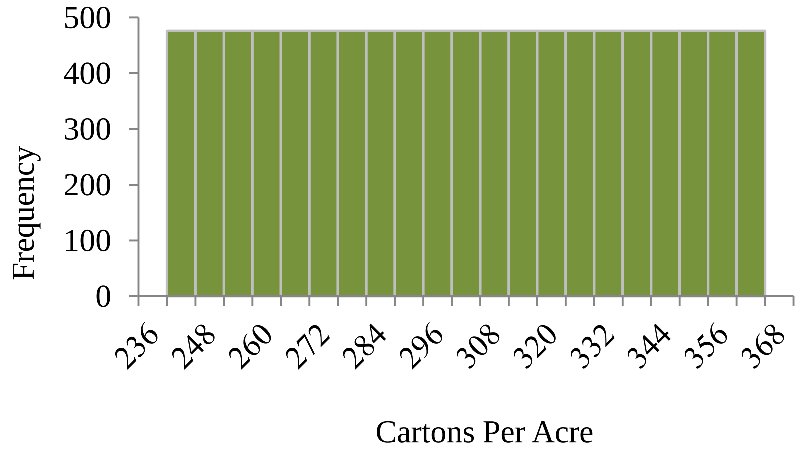

Figure A.2. Example of a Uniform Distribution

Normal Distribution

Normal distributions have bell shaped curves. When data is normally distributed, 68% of the observations will fall within 1 standard deviation from the mean, 95% will fall within 2 standard deviations from the mean, and 99.7% will fall within 3 standard deviations from the mean. The normal distribution is defined by its mean and standard deviation. The mean is

(A.11) $$\mu = \frac{\sum_{i=1}^{n} x_i}{N}.$$

The variance is

(A.12) $$\sigma^2 = \frac{\sum_{i=1}^{n} (x_i - \mu)^2}{N},$$

while the standard deviation is

(A.13) $$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \mu)^2}{N}}.$$

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