Can Florida's citrus industry be saved while preserving the environment? An economic analysis for the bio-control of the Asian Citrus Psyllid

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Selected Paper prepared for presentation at the Southern Agricultural Economics Association's 2015 Annual Meeting, Atlanta, Georgia, January 31-February 3, 2015

Introduction

Citrus greening disease or Huanglongbing (HLB) is a destructive vector-borne disease that affects all varieties of citrus and is currently threatening the existence of Florida's citrus industry. While HLB was not discovered in Florida until August 2005 (Bove, 2006), its vector has been present in the state since at least 1998 and was widely spread throughout most citrus producing regions of the state by 2003 (Halbert & Manjunath, 2004). The disease has spread rapidly and is now present in every citrus producing county in Florida, as well as citrus producing regions of Brazil, Africa, the Middle East, the Indian subcontinent, and Southeast Asia (Bove, 2006).

There is no known cure for HLB, and the three major components of traditional HLB management include control of the insect vector through chemical or other means, aggressive removal of infected trees to reduce sources of disease within groves, and planting of disease-free nursery stock (Grafton-Cardwell, et al., 2013). However, Florida producers have been reluctant to follow the traditional three-tiered approach and have chosen not to remove diseased trees if they remain productive. Instead, some growers have recently implemented a strategy to supply diseased trees with macro and micro nutrients through foliar sprays (Hall, et al., 2013).

In this paper, we examine the costs and benefits of vector control through biological means. While the favored method controlling the insect vector of HLB is through insecticide use, there are a number of organisms that are known predators or parasites of the vector. One of these organisms, the parasitic wasp *Tamarixia radiata*, is reared by the Florida Department of Agriculture and Consumer Services (FDACS) for mass release and is provided to citrus producers and others free of charge.

The HLB Disease and its Impact in Florida

HLB is caused by phloem-restricted bacteria of the *Candidatus* Liberibacter group, of which three different species are known to occur: an Asian strain (*Candidatus* Liberibacter asiaticus), an African strain (*Candidatus* Liberibacter africanus), and a strain found only in Brazil (*Candidatus* Liberibacter americanus). These three species of bacteria can be transmitted by two species of citrus psyllids, the Asian citrus psyllid (*Diaphorina citri*), and the African citrus psyllid (*Trioza erytrae*), although the bacterial and vector species are geographically isolated and only overlap in a few locations such as the islands of Mauritius and Reunion in the Indian Ocean (Bove, 2006).

In Florida's HLB outbreak, *D. citri* is the only vector present and *Ca*. L. asiaticus is the bacterial species identified as causal agent (Bove, 2006; Hall, et al., 2013). Trees infected with HLB first exhibit yellow shoots and blotchy mottle leaves reminiscent of nutrient deficiencies, and fruit in affected branches are small, lopsided, produce aborted seeds, and do not change color properly (Bove, 2006). As the disease progresses, the tree loses productivity as entire branches, and then the whole tree, dies. If the disease is widespread, citrus trees may live for only five to eight years and never produce usable fruit (Halbert & Manjunath, 2004).

The Asian citrus psyllid depends heavily on new flush from citrus and related tree species for survival and reproduction. *D. citri* females deposit their eggs only on young tissue and can lay up to 800 eggs during their lifetime. Eggs hatch in four days or less, and the larval stage consists of five instars that are completed in 15 days or less, after which mature adults emerge. The length of the life cycle is dependent on temperature, but normally lasts between 15 and 47 days (Grafton-Cardwell, et al., 2013).

While *D. citri* are considered poor fliers and can only fly over distances of one mile or less in several days, their long range dispersal is aided by prevailing winds and unintended human transport of host plant material. For instance, it is believed that natural dispersal alone—aided by prevailing winds—is responsible for the spread of HLB-carrying psyllids from urban coastal southeast Florida to commercial citrus groves in Hendry county, which is located more than 50 km away on the opposite end of the Florida Everglades, an area with no known psyllid hosts (Hall, et al., 2013). It is also believed that *D. citri* was able to establish widely in Florida as a result of shipments of the ornamental bush orange jasmine (*Murraya paniculata*) infested with Asian citrus psyllid nymphs and adults that were grown in southern Miami-Dade county and were later sold in discount chain stores throughout the state (Halbert & Manjunath, 2004).

Even though HLB is a vector transmitted disease, there are a number of features of this disease system that make its control especially complex. For example, once a healthy tree is inoculated with the disease, there is a latency period that can last between six and 12 months in which the tree exhibits no symptoms but may act as a source of the disease (Bove, 2006). This problem reduces the effectiveness of management strategies in which diseased trees are removed to eliminate sources of the disease within the grove (Grafton-Cardwell, et al., 2013).

The feeding and breeding behavior of *D. citri* also plays an important role in the spread of the disease. *D. citri* adults prefer the emerging plant tissue—known as flush—for food, and breeding and oviposition occur only in fresh flush (Halbert & Manjunath, 2004). This preference for fresh flush makes young trees particularly susceptible to infestation by psyllids and hence to inoculation with the HLB pathogen. Trees infected with HLB produce yellow shoots and release a volatile methyl salicylate compound, both of which attract *D. citri* adults. However, since HLB infected tissue has a relatively poor nutritional content, adult psyllids quickly move on to flush in healthy nearby trees (Grafton-Cardwell, et al., 2013). Psyllids carrying the HLB bacteria have also been found to develop faster and lay more eggs, resulting in more rapid population growth (Hall, et al., 2013). Female psyllids can also acquire the HLB bacterium through sexual contact with infected males, and female carriers of HLB transmit the bacteria to their offspring during oviposition (Hall, et al., 2013).

The transmission of the HLB bacteria from infected trees to psyllids, and from psyllids to healthy trees also follows some interesting dynamics. For instance, the transmission efficiency of HLB from carrier adult *D. citri* to healthy trees is highly variable, ranging between 1% to 80% (Halbert & Manjunath, 2004). There is also a latency period between the moment in which an adult psyllid acquires the pathogen and the time in which the psyllid can infect a healthy tree (Grafton-Cardwell, et al., 2013). There is also a large difference in transmission efficiency between psyllids that acquire the HLB pathogen as adults and those that acquire the bacteria during the egg or larval stages, with the latter having significantly higher transmission efficiencies (Hall, et al., 2013). In addition, psyllids that acquire the HLB bacteria during the larval stage can transmit the pathogen as soon as they emerge as adults (Halbert & Manjunath, 2004).

While the true impact of HLB on citrus production in Florida is difficult to determine, it is clear that disease has had a significant impact in the decline of citrus in the state (Figure 1). Citrus acreage peaked in 1995 at 815 thousand acres, and declined slowly until 2001, when 718 thousand acres were planted in citrus throughout the state. There has been a marked acceleration in the decline of citrus acreage since that time, and by the 2012-13 season, less than 490 thousand acres of citrus remained in production. Statewide citrus production has suffered a similar decline, going from 304 million boxes in the 1997-98 season to 156 million boxes in the 2012-13 season. All told, citrus acreage has decreased by 40% and production by 49% since their historical peaks, all of which occurred in the last 20 years.

There are a number of factors that have contributed to this observed decline in acreage and production of citrus in Florida. In addition to HLB, citrus canker, another introduced bacterial disease, has been affecting commercial citrus groves in Florida since 1995 (Dewdney, et al., 2001). Recent changes in consumer preferences towards beverages with high sugar contents may also be playing a part in the decline of Florida’s citrus production, of which a vast majority is destined for processed juice products. However, a rare positive note is the finding that orange juice made with fruit from symptomatic trees is of similar quality as that made with fruit from healthy trees (Plotto, et al., 2010).

Monetary estimates of the impact of HLB on Florida citrus have begun to emerge in recent years. Hodges and Spreen (2012) use a programming model of the global citrus market to estimate the price and quantity of orange juice that would have been observed in the absence of HLB and compare it with the actual price and quantity between the 2006-07 and the 2010-11 harvest seasons, and estimate a production loss of $1.7 billion over this five year period. Similarly, Moss, et al. (2014) develop estimates of lost producer and consumer surplus as a result of the current outbreak of HLB, and conclude that in the 2012-13 season, consumers and producers lost an estimated $1 billion. Some of the economic challenges of HLB in Florida are further summarized in Farnsworth, et al. (2014).

HLB Management in Florida

Current strategies for citrus disease management in Florida have been shaped by previous efforts to control and eradicate diseases of citrus in the state, in particular the effort to eradicate the citrus canker bacteria, *Xanthomonas axonopodis*. This pathogen was detected in residential areas surrounding Miami International Airport in 1995, and a joint Federal and State government eradication program was rapidly developed and implemented. This program called for the removal of all diseased citrus trees, in addition to all citrus trees within 1,900 feet of diseased trees. The United Stated Department of Agriculture (USDA) administered the eradication program for commercial groves and provided compensation of $26 per removed tree to affected producers. Similarly, the Florida Department of Agriculture and Consumer Services (FDACS) was tasked with administering the eradication program for residential orchards and provided compensation of $55 per removed tree. However, legal challenges from homeowners were filed very early in the eradication program, and by the year 2000 the courts halted the eradication program in residential areas (Adams, et al., 2007). Eradication was finally declared infeasible in 2006 after severe hurricane seasons in 2004 and 2005 had aided the spread of the pathogen throughout all citrus producing areas in the state, and legal action by homeowners seeking further compensation for loss of trees continues to this day. The problematic precedent set by the citrus canker controversy in Florida from a disease management perspective is that the state has very limited powers when it comes to eradicating citrus diseases if tree removal is required.

Traditional management of HLB includes control of the psyllid vector, aggressive removal of infected trees to reduce sources of the disease, and planting with HLB-free nursery stock. This management scheme has proven successful in the fight against HLB in Brazil and has resulted in drastic reductions in the proportion of symptomatic trees (Bove, 2006). While this three pronged approach was advocated early on in Florida’s HLB outbreak, it was deemed to be too expensive by most producers, who instead decided to maintain symptomatic trees as long as they were bearing usable fruit (Hall, et al., 2013). Given the precedent set by the citrus canker eradication program, the state is unable to force the removal of diseased trees to curtail the spread of the pathogen. Instead, many producers have even adopted a regime of nutritional supplements provided to symptomatic trees through foliar applications (Salifu, et al., 2012), although evidence of the effectiveness of these programs is anecdotal and controlled trials have not shown significant benefits (Gottwald, et al., 2012).

There are a couple institutional aspects of citrus disease management in Florida that are worth mentioning. First, citrus disease management in the state is governed by the Citrus Health Response Plan (CHRP), a policy developed jointly by FDACS and USDA in consultation with the citrus industry. Recognizing that Florida’s citrus industry is at particular risk of potentially damaging biological invasions and that eradication of these pathogens and pests is not always feasible, these organizations developed the CHRP as a plan that emphasizes prevention and management of disease through registration, inspection, and certification of entities involved in the production and commercialization of citrus, from nurseries and budwood facilties to processors and distributors of fresh citrus and other citrus products (USDA/APHIS and FDACS, 2006). All citrus disease management strategies in the state are funded and implemented under the auspices of the CHRP.

Second, the state of Florida established a series of Citrus Health Management Areas (CHMA) in response to recommendations by a National Research Council panel tasked with developing strategies to help the state cope with HLB (NRC, 2010). The primary objective of the CHMAs is to provide regional coordination for insecticide sprays to control populations of the Asian citrus psyllid by removing sources of refuge and re-infestation (Jones, et al., 2013). Both of these policies ensure that Federal and state agencies are constantly inspecting and monitoring populations of Asian citrus psyllids throughout the state, and that this monitoring takes place in a decentralized manner by focusing on particular CHMAs.

Conventional citrus groves in the state have adopted a regime of heavy pesticide use for controlling *D. citri* populations that involves 8 to 12 foliar applications annually (Farnsworth, et al., 2014). The most effective chemicals for control of Asian citrus psyllids have proven to be the broad-spectrum pesticides such as pyrethroids, organophosphates, and neonicotinoids (Grafton-Cardwell, et al., 2013). In recent years, regionally coordinated insecticide sprays through the CHMAs during the winter, when low temperatures slow down the life cycle of psyllids to near dormancy have been especially effective at reducing *D. citri* numbers in commercial groves (Jones, et al., 2013).

In addition to heavy insecticide use throughout the year to control the psyllid vector of HLB, many conventional groves are also implementing a nutritional supplementation regime that is applied through foliar sprays. This type of foliar supplementation of macro and micro nutrients has yielded positive effects with other annual crops suffering fungal and bacterial diseases, but any benefits it may have on HLB infected citrus is only anecdotal, and controlled trials have thus far failed to show significant benefits (Gottwald, et al., 2012). This strategy has the added problem of ensuring a buildup of HLB inoculum in the grove, thereby threatening the success of reset plantings (Spann, et al., 2010).

Another component of HLB management in Florida is the control of *D. citri* populations through the introduction of natural enemies from its native range. In particular, two parasitic wasps from Asia and the Indian subcontinent were introduced to Florida in 1999, shortly after the discovery of the Asian citrus psyllid. These wasps, *Tamarixia radiata* and *Diphorencytrus aligarhensis* lay their eggs inside or on the surface of *D. citri* larval nymphs, and once the eggs hatch the larval form of the wasps parasitizes and kills the *D. citri* nymph. While both wasps were introduced at the same time, only *T. radiata* has successfully established in Florida, and today can be found in commercial citrus groves throughout the state (Grafton-Cardwell, et al., 2013). It is important to note that both of these wasps are host specific parasitoids of *D. citri* and they require the presence of Asian citrus psyllid nymphs for completion of their life cycle. In the absence of *D. citri* nymphs, both of these wasps would be incapable of reproducing and hence would be subject to local extinction.

Biological Control of HLB in Florida

Biological control is the study, importation, augmentation, and conservation of natural enemies to regulate the population densities of pests or disease pathogens. These methods can be categorized under three general approaches that include importation, augmentation, and conservation (Orr, 2009). Importation biological control, also known as classical biological control, involves the identification of a natural enemy from an invasive pest's native range and the subsequent importation and release of the natural enemy in the introduced range. Conservation biological control involves the modification of production practices to enhance survival of natural enemies, and includes modification of pesticide regimes and manipulation of habitat through special plantings and tilling practices. Augmentation biological control involves the mass rearing of natural enemies to 'augment' their populations at crucial periods to suppress pests.

Biological control efforts against the Asian citrus psyllid in Florida began simply as a classical approach with the importation and release of *T. radiata* and *D. aligarhensis* in 1999, just one year after the initial detection of the psyllid. Of these two parasitic wasps, only *T. radiata* became widely established (Qureshi, et al., 2009), possibly due to competition between the two parasitoids (Grafton-Cardwell, et al., 2013). In recent years, FDACS has improved the methodology of mass rearing *T. radiata* to the point where an augmentative release biological control program has become feasible. In addition to *T. radiata*, a number of insects native to Florida are known predators of *D. citri*, including several species of ladybeetles and spiders (Michaud, 2004).

FDACS operates two facilities dedicated to the mass rearing of *T. radiata* wasps for release throughout Florida's commercial citrus groves and residential areas. The smaller facility, located in Gainesville, on the northern edge of Florida's citrus growing region, produces an estimated 125,000 *T. radiata* adults each month, with no space for additional expansion. A new facility located in the central Florida community of Dundee, right in the heart of the state's citrus producing region, currently produces an estimated 150,000 *T. radiata* adults, but is set to expand and increase its rearing capacity by a factor of three (Eric Rohrig, Director of FDACS Biocontrol Lab, personal comm.).

Adult parasitic wasps are offered completely free of charge to producers and homeowners interested in using augmentative releases of *T. radiata* to control populations of Asian citrus psyllids in their property. While a majority of commercial citrus groves are under heavy insecticide regimes that preclude the survival and establishment of *T. radiata*, producers following organic practices and low or no insecticide spray regimes can benefit from augmentative releases of *T. radiata* as a means to control psyllid populations. There is also a temporary need for non-toxic psyllid control during the spring flush season when citrus trees are also blooming, as heavy insecticide sprays will also result in low pollination rates and hence low fruit yields (Kerr, et al., 2014).

There is also an important component of the CHRP program that relies on *T. radiata* wasps reared in FDACS facilities. Through the surveys conducted under CHRP, state officials and extension scientists can identify certain locations as "hotspots" where psyllid counts are abnormally high, indicating large population densities of the HLB vector (Jones, et al., 2013). These surveys also allow the identification of abandoned groves or feral citrus located in private property, and where the landowner cannot be reached or is not willing to cover the expense of insecticide sprays (Kerr, et al., 2014). In these cases, augmentative releases of *T. radiata* by CHRP field inspectors and other interested individuals can reduce psyllid populations.

Costs of Florida's T. radiata Mass Rearing Program

The operational costs of Florida's *T. radiata* mass rearing program have been documented by Kerr, et al. (2014), who separate these costs by different categories and by facility (Table 1). Each of these facilities employs one biological scientist and three laboratory technicians, which comprise over 75% of the operational costs of the program. The remaining portion of the operational costs are dominated by shipping—which includes charges for overnight shipping of live wasps to requesting parties and pre-paid return service postage for the shipping materials—and other supplies that include soil, pots, pesticide, fertilizer, and light bulbs. The total annual costs for the operation of the program are estimated to be $361,529.

Benefits of Florida's T. radiata Mass Rearing Program

Evaluating the impact that the mass rearing and augmentative release of *T. radiata* has had on Florida's HLB epidemic is an amazingly complex task that has yet to be undertaken. Measuring the effectiveness of augmentative releases of *T. radiata* would require a Herculean effort of testing every tree for the disease and performing insect counts for a long time period—all while maintaining the citrus grove closed to the outside world to prevent introduction of infected psyllids from outside the experimental area—and the funding thus far has not been forthcoming for a study of that magnitude (Eric Rohrig, personal communication). Up to date, the most comprehensive study of the impact of *T. radiata* is Michaud's (2004) field survey of natural mortality of *D. citri* in central Florida.

To determine the relative contribution of *T. radiata* to juvenile psyllid mortality, Michaud (2004) surveyed citrus trees in several central Florida commercial groves to determine infestation by *D. citri* nymphs, and surveyed infested trees continuously to determine natural mortality rates of juvenile psyllids, as well as the relative contribution of different natural enemies to psyllid nymph mortality. To determine the contribution of *T. radiata* parasitism in particular, Michaud set up a set of field cages that would allow *T. radiata* adults to move in and out, but would prevent all other natural enemies from reaching the nymphs contained in the cage.

The results from this field experiment are quite remarkable in that they show two surprising findings. First, *T. radiata* is but a minor contributor to natural mortality of psyllid juveniles in Florida, and only about 1% of natural psyllid mortality can be attributed to *T. radiata* parasitism.

Second, Florida has a large number of native organisms that are taking advantage of the presence of the Asian citrus psyllid and using them as a source of food. These organisms, which include ladybeetles, spiders, and ants, are altogether responsible for natural mortality rates in juvenile *D. citri* as high as 90% (Michaud, 2004). It is important to note, however, that there were no augmentative releases in any of Michaud's (2004) study areas, and at the time the *T. radiata* biological control program in Florida was limited to a classical approach. Therefore, the results of a similar study in a commercial grove following augmentative releases may yield different results. Similarly, Michaud's (2004) study measured the impact of natural enemies on *D. citri* mortality, but their impact on the spread of HLB was not assessed since HLB had not been yet detected in Florida at the time.

Even in the face of Michaud's (2004) findings, the new reality of increasing resistance to pesticides is in itself a good reason to continue developing a biological control program for Asian citrus psyllid in Florida. For instance, Tiwari et al. (2011) found lower susceptibility to commonly used insecticides such as bifenthrin, carbaryl, chlorpyriphos, fenpropathrin, imidacloprid, spinetoram, and thiamethoxam in Asian citrus psyllid populations from commercial groves collected in 2009 and 2010 than in a control laboratory-reared population established with insects collected in 2000. The fact that psyllid populations exposed to insecticides can develop resistance to these chemicals in 10 years or less highlights the importance of an integrated pest management approach for the future fight against HLB in Florida.

Natural enemies of the Asian citrus psyllid, including *T. radiata*, also play an important role in controlling both the vector and the spread of the HLB pathogen in urban and suburban environments, where homeowners are unlikely to use insecticides and *D. citri* populations would grow unchecked in the absence of its natural enemies. In fact, citrus trees in urban and suburban areas are known to be important latent sources of disease, and high foreclosure rates, which are associated with poorly or unmanaged landscaping, are known to facilitate the spread of Asian citrus psyllids (Richards, et al., 2013). Therefore, releases of *T. radiata* in commercial orchards may be providing a positive externality to dooryard citrus owners by helping to establish populations of the parasitic wasps that can migrate to urban and suburban areas. But more importantly, releases of *T. radiata* in urban and suburban areas may provide commercial citrus growers a sizable positive externality by reducing latent psyllid populations and mitigating the spread of HLB.

Weighing costs and benefits

While it is still unclear if the benefits of the *T. radiata* mass rearing and augmentative release program exceed its costs, we can definitely state that the parasitic wasp *T. radiata* is not the silver bullet that biological control enthusiasts and Florida's citrus producers were hoping for. It is very likely that *T. radiata* is exerting significant pressure on Asian citrus psyllid populations throughout the state, especially through the augmentative release of parasitic wasps at critical periods of citrus flushing and psyllid oviposition. Similarly, the augmentative release of *T. radiata* wasps may be the only reasonable way to control psyllid populations during citrus blooming periods, when use of insecticides would cause severe mortality in pollinating insects and therefore result in lower fruit yields.

Discussion

Our evaluation of Florida's *T. radiata* mass rearing program illustrates the difficulty in measuring the net benefits of biological control programs that do not result in complete suppression of the target pest. An additional difficulty in measuring the net benefits of the program stems from the complexity of the HLB disease system, where inducing a 90% juvenile mortality rate of the target pest—the vector of the HLB pathogen—does not result in meaningful reductions in the incidence of the disease.

Field experiments have shown that classical biological control of *D. citri* using *T. radiata* as an introduced control agent result in suppression of the target pest—albeit causing relatively low mortality rates. However, given that *T. radiata* requires Asian citrus psyllid nymphs for completion of its life cycle, its mere persistence in Florida's citrus groves is an indication that the parasitic wasps are an effective natural enemy of *D. citri*. Therefore, it is clear that natural enemies—native generalist predators and introduced parasitic wasps—account for significant suppression of Asian citrus psyllid populations.

The effectiveness of mass rearing and augmentative releases of *T. radiata* in mitigating the impacts of HLB are perhaps best assessed in comparison to the other available options for managing and controlling the disease. Federal and state agencies, universities, and Florida citrus growers have spent a considerable amount of resources in the fight against HLB. A large number of strategies have been implemented, including heavy insecticide use, quarantines, and nutritional supplements for diseased trees. Similarly, sizable financial resources are currently being devoted to research of new alternatives including genetic modification, search for resistant varieties, and the use of antibiotics for the treatment of diseased trees. However, it would be difficult to argue that any of these alternatives has proven more effective than the *T. radiata* mass rearing program at slowing the spread of HLB. In other words, the biological control program has been as effective—or as ineffective—as all other available alternatives in the fight against HLB.

It is also clear that Florida's mass rearing and release program for *T. radiata* has not been as successful as some other biological control programs. However, of the three reference points of success for biological control initiatives mentioned by Orr (2009), Florida's *T. radiata* program meets two. The first goal of a biological control program is to achieve establishment of the control agent, and only 34% of programs achieve this goal. In this aspect Florida's program has been a tremendous success, as the range of *T. radiata* in the state is as extensive as that of the Asian citrus psyllid. The second objective of biological control is to achieve some level of pest suppression, and in this Florida's program has also been successful, joining the 42% of biocontrol initiatives that have also achieved this goal. The last objective, complete suppression of the target pest, was not achieved in our case. However, only 16% of programs have achieved this mark.

Florida's *T. radiata* mass rearing program is largely funded by the Federal government through the USDA-APHIS CHRP program. In fact, there are similar federally funded mass rearing program in Texas and California using either or both *T. radiata* and *D. aligarhensis* as biological control agents. However, under the leadership of FDACS Division of Plant Industry, the state of Florida has devoted most of this funding to improvements in human and physical capital, rather than simply to the mass rearing of parasitic wasps. Specifically, Florida has used CHRP funds earmarked for Asian citrus psyllid biocontrol to develop new and improved processes for the rearing of biological control agents and the construction of greenhouses and laboratories used for the mass rearing process in a highly controlled environment. Conversely, other states have used these funds to produce parasitic wasps in less controlled field environments, such as in citrus trees covered by nets. Therefore, regardless of the outcome of the biological control program, the state of Florida has gained state-of-the-art facilities and know-how that can be used in future biological control programs.

After nearly 10 years since the arrival of HLB in Florida, it is becoming evident that a silver bullet against the disease will continue to elude citrus producers for the foreseeable future. Perhaps a wise strategy would be to develop a new management approach whose objective is not to eradicate or cure HLB, but to live with it and still maintain productive orchards. Such a strategy is likely to include several of the approaches currently available, but will also require producers to change some of the approaches currently being used to manage HLB. And it is very likely that biological control, either through the mass rearing or simply through the conservation of native and introduced natural enemies of the Asian citrus psyllid, will be a part of such a strategy.

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Tables

Table 1. Annual costs of Florida's *Tamarixia radiata* mass rearing program. Source: (Kerr, et al., 2014)

Dundee Facility	
Item	**Cost**
Labor	$147,000.00
Electricity	$19,000.00
Phone	$724.29
Propane	$2,009.13
Other Utilities	$1,795.80
Shipping	$6,000.00
Supplies	$15,000.00
Subtotal	*$191,529.22*

Gainesville Facility	
Item	**Cost**
Labor	$129,000.00
Electricity	$20,000.00
Shipping	$6,000.00
Supplies	$15,000.00
Subtotal	*$170,000.00*

TOTAL	**$361,529.22**

Figures

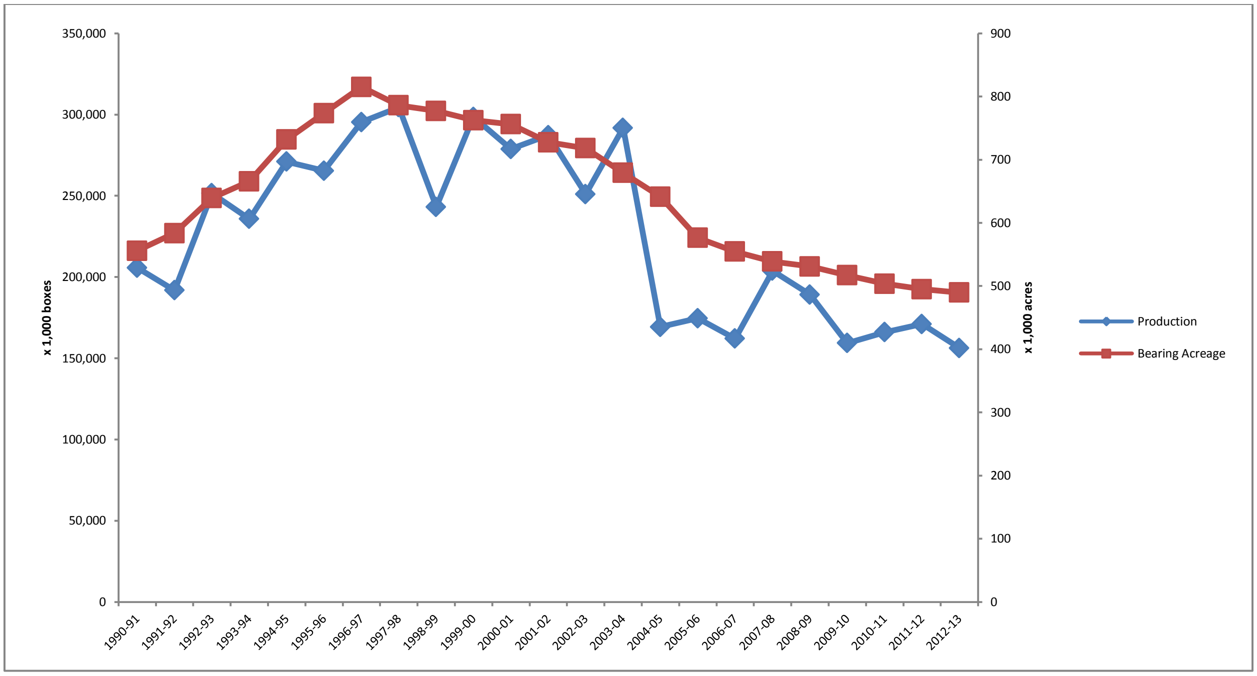

Figure 1. Citrus production and bearing acreage in Florida, 1991-91 – 2012-13. Source USDA-NASS.