Sam Houston State University
Department of Economics and International Business
Working Paper Series

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SHSU Economics & Intl. Business Working Paper No. 14-12
December 2014

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Predicting the Total Economic Impacts of Invasive Species

The case of the Red Streaked Leafhopper

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Key Words: total economic impacts, direct impact, indirect impact, induced impact, invasive species, IMPLAN input-output model

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I. Introduction

The accelerating frequency of non-native species invasions has caused tremendous environmental and ecological damage and has led to many new challenges. For the purposes of pre-invasion prevention or for intervention after species establishment, estimates of the associated total economic impacts are crucial for policy-makers to gauge and target responses to invasions. In invasive species management, prevention is the "first line of defense" and the most cost-effective approach (The National Invasive Species Council, 2014). Effective prevention and early intervention call for coordinated efforts from the government, local agencies and other interest groups. Accurate estimates of total economic impacts better motivate interested parties and provide incentives for early response. Providing such estimates can be challenging, however, since a forward-looking approach is needed. This paper provides a framework for rigorously estimating the total economic impacts of invasive species. The approach could be applied to any species invasion, but is especially useful before the invasion is fully realized.

Efforts have been made to estimate the losses or economic impacts of many invasive species. For example, Pimentel, Zuniga, & Morrison (2005) estimate that aggregate annual losses from invasive species in the U.S. are approximately $120 billion. Global costs are estimated to be around $1.5 trillion (Pimentel, et al., 2001). Such estimates are calculated after the invasive species is fully established and losses are almost fully realized. At this point, any response to the invasion is likely to be less effective and more costly than an earlier response would have been. Even for estimating fully realized economic impacts, these estimates in previous literature still suffer from two major issues. First, total economic impacts extend far beyond what current estimates include. Current estimates are usually calculated as the sum of losses in production reported by the various directly affected industries and reported costs incurred in efforts related to control or prevention.

These losses and costs are typically referred to as the direct impacts of the invasion. We show that direct impacts may only constitute about half of total economic impacts. Total economic impacts should also include: (1) the losses to other related businesses that use the products from the affected industries as inputs in their production, commonly known as downstream industries; (2) the losses to businesses that supply their products to the affected industries as inputs, commonly known as upstream industries; (3) the general societal impact resulting from the reduced spending of individuals who rely on the directly and indirectly affected industries for income. The losses to closely related industries in points (1) and (2) are, together, typically referred to as indirect impacts in the input-output model literature. The broader impacts from reduced individual spending are referred to as induced impacts in this literature. Total economic impacts are calculated as the sum of direct, indirect, and induced impacts.

The second issue with current calculations of economic impacts is that, by focusing only on directly affected industries, these estimates fail to capture how these impacts are actually shared societally in the form of lost income, jobs, and tax revenues. Understanding the societal dispersion of impacts is the only way to justify the appropriate societal response to the invasion.

In contrast to previous literature, the framework proposed in this paper is capable of predicting the invasion of the non-native species, estimating the total economic impacts over the short-run and long-run horizons, and breaking down the total economic impacts across a variety of societal dimensions. An earlier estimate of economic impacts, along with a fuller picture of their magnitude and dispersion, will allow for a more effective response to both existing and future invasions.

Our approach is then applied to the case of the Red Streaked Leafhopper (Balclutha rubostriata, henceforth "leafhopper"), a grass-feeding insect which can carry a phytoplasm capable of decimating sugarcane crops. Currently the leafhopper is established along the Gulf coast of Texas and has spread to the edge of the sugarcane growing regions of Louisiana. Results show that the value of lost sugarcane (direct impact) after 15 years is estimated to be approximately $16 million annually without the phytoplasm and $205 million annually with the phytoplasm present.[1] Total economic (direct, indirect, and induced) impacts after 15 years are estimated at nearly $30 million ($370 million) without (with) the phytoplasm. Also at the 15-year mark, the leafhopper alone is predicted to lower annual tax revenues by over $500,000 and to cost the Louisiana economy over 125 jobs. With the phytoplasm present, tax revenues are lowered by more than $6.5 million and over 1,500 jobs are lost.

After 25 years, the model suggests that the leafhopper will have spread almost completely through the relevant parts of Louisiana. At this point, direct impacts are estimated at $75 million ($950 million) annually without (with) the phytoplasm, while total annual economic impacts are estimated at $133 million ($1.7 billion). Lost tax revenues are over $4 million annually without and over $50 million with the phytoplasm; lost jobs are estimated at over 800 from the leafhopper and over 10,000 with both the leafhopper and phytoplasm.

The rest of the paper is structured as follows. Section II discusses the related literature on the economic impacts of invasive species and input-output models, and the background on Leafhopper and sugarcane in Louisiana. Section III presents the framework for the estimation of total economic impacts with an application to the leafhopper. Section IV presents the application results and Section V provides discussion. The final section concludes.

II. Related Literature and Background

[1] All results reported are in 2013 USD.

1. Literature on the Economic Impacts of Invasive Species

In 1993, the U.S. Congress's Office of Technological Assessment published a report estimating that from 1906 to 1991, a small number of invasive species for which estimates were available had cost the nation $97 billion in lost production and control expenses (OTA, 1993). This report was one of the earliest attempts to measure the aggregate impacts of one or more invasive species. The report stresses that this number is very conservative, as estimates weren't available for a majority of harmful invasives, including some of the most costly.

More recently, Pimentel, Zuniga, and Morrison (2005) estimate that the approximately 50,000 invasive species in the United States cause almost $120 billion in annual damages and losses. Extrapolating from the losses estimated in six nations studied, Pimentel et al. (2001) estimate that global damages and costs from invasive species exceed $1.4 trillion annually. Perrings et al. (2002) and Lovell and Stone (2005) have partial lists of the many species whose costs have been studied individually. These existing studies have come to their respective estimates (of direct impacts only) by collecting and aggregating existing damage estimates as well as control costs, where available. Thus, their estimates only reflect part of the total economic impact and can be misleading when making control or prevention decisions. It is pointed out in Horan et al. (2002) that historically, responses are often limited to control or adaptation since prevention and eradication are usually no longer possible by the time the invasion's direct economic impacts are large enough to warrant a sufficient response. However, if total economic impacts are estimated ahead of time, prevention and eradication will certainly be economically justified.

Cook et al. (2007) introduce a bioeconomic model that allows for estimation of (direct) economic impacts prior to the arrival of the invasive species. Alternatively, one could interpret their results as the value of damages avoided if an invasion can be prevented. Examining the potential invasion of the varroa bee mite in Australia, the authors conclude that preventing the invasion would avoid direct impacts of $16.4 to $38.8 million annually. This approach is the first step towards estimating economic impacts of non-native species before the invasion, which in turn is critical for cost-benefit analysis in environmental management. In theory, control or prevention measures are economically justified when the associated cost does not exceed the total expected economic impact avoided when such measures are taken (the benefits of control or prevention). However, to correctly carry out the cost-benefit analysis, the expected direct impacts, like those estimated in Cook et al. (2007), need to be transformed into the total expected impacts.

The transformation from direct economic impacts to total economic impact can be accomplished using input-output models. Input-output models are common in a number of fields but not in the study of invasive species. Applications of these models include estimates of the net benefits of tourism, major sporting events like the Olympics or the FIFA World Cup, the regional economic benefits of universities, military bases, or corporations, and estimates of the total societal costs of certain diseases. One exception in the study of invasive species is Juliá, Holland, and Guenthner (2007), which uses input-output models to estimate the total economic impact of the invasive yellow starthistle in Idaho. While their estimation accounts for the direct, indirect, and induced economic impacts, our approach goes further by including the tax and employment effects and modelling economic impacts before the invasion.

The approach in this paper combines a forward-looking model of an impending invasion with an input-output model to estimate the full range of total economic impacts. These total impacts are further broken down across a number of dimensions to capture how these effects are shared across groups in society.

2. Background on the Leafhopper and Sugarcane in Louisiana

The Red Streaked Leafhopper (Balclutha rubrostriata) is a small, grass-feeding insect native to Sri Lanka and India which has spread to much of East Asia and the Pacific Rim, several African countries, the eastern Mediterranean, Central America, Cuba, and Puerto Rico (Morgan, Smith-Herron, & Cook, 2013). The leafhopper has several potential layers of economic importance through its effects on sugarcane, one of the grasses it prefers to feed upon. Leafhoppers damage sugarcane through sap removal when they feed, lessening crop yields (Long & Hensley, 1972). Of greater concern is the fact that the leafhopper has been identified as a carrier of the phytoplasm that causes sugarcane white leaf disease (Hanboonsong, Ritthison, Choosai, & Sirithorn, 2006), which is capable of causing up to 100% crop loss in some areas (Rishi & Chen, 1989). Related leafhoppers transmit at least seven other economically important diseases, and the Red Streaked Leafhopper may be capable of transmitting these as well (Knight & Webb, 1993; Morgan, Smith-Herron, & Cook, 2013).

The first positive identification of the red streaked leafhopper in the continental United States came from samples collected in Bexar County, Texas in 2008 (Zahniser, Taylor, & Krejca, 2010). The leafhopper was found to be the dominant component in the samples, making up almost 85% of collected specimens. Morgan, Smith-Herron, and Cook (2013) sampled for the leafhopper along the Texas gulf coast and on into Louisiana. The study confirmed the presence of the leafhopper in fifteen Texas counties and one Louisiana parish.

Sugarcane production and processing is a major contributor to Louisiana's economy.[2] According to the American Sugar Cane League, Louisiana is one of the major sugarcane growing

[2] Louisiana is the second largest sugarcane growing state while Texas is the fourth largest. The framework described in this paper can also be applied to the case of Texas with the initial presence of the leafhopper and the sugarcane growing counties in Texas.

states in the U.S., with more than 400,000 acres of sugarcane in 22 parishes. Approximately 13 million tons of sugar are produced each year and about 17,000 employees work in the sugarcane industry in Louisiana. Given the presence of the leafhopper in the Louisiana parish and the importance of sugarcane production in the state, correctly predicting and estimating the total economic impact of the leafhopper is both urgent and important.

3. Models

The framework proposed in this paper involves three steps. First, an appropriate biological model is selected to predict the spread of the invasive species. Various biological models have been developed to predict the invasion of non-native species, but there is no universal model that can be applied in every case. While it is beyond the scope of this paper to discuss the selection of appropriate biological models, the reader is referred to Elith (2012) for a discussion of various alternatives. The appropriate biological model will provide the predicted distribution of the invasive species at various locations for each point in time. Second, using the distributions, we can estimate the expected direct impacts of the species at each location and time. Finally, an input-output model is selected to estimate indirect and induced impacts from the projected direct impacts.[3] In addition, it is also important to break down total impacts geographically and societally to examine the economic impact from various perspectives. This three-step approach applies to situations in which the invasive species is anticipated to spread or in the early stage of spreading. For evaluating the economic impacts of fully established invasive

[3] There are other economics models that can be used to estimate economic impacts, such as the general equilibrium model.

species, only the final step of the approach is needed. The remainder of this section applies this framework specifically to the case of the Red Streaked Leafhopper.

1. Predicting invasion of the leafhoppers in Louisiana

The prediction begins with the confirmed location of the leafhopper in Louisiana and predicts its potential spread throughout the sugarcane growing regions of the state using Monte Carlo simulation. First, satellite imagery is used to identify growing regions throughout Louisiana at a time when these crops are the only vibrantly green plants in the state.[4] Then a grid is placed over the sugarcane fields, which breaks the area into 26,929 unique parcels, each with a maximum size of 24 acres. Together, these parcels account for 417,361 acres of sugarcane. Figure 1 is a map of the identified sugarcane growing regions in Louisiana. The parcel containing the confirmed leafhopper is in Rapides parish, and it is expanded and highlighted.

[Insert Figure 1 Here]

Given the initial presence of the leafhopper in this single parcel, the probability that the leafhopper spreads from one parcel to another is assumed to be a function of the distance between the two parcels[5]. Specifically, the probability of spread from one parcel to another that is x units away is given by an exponential function with the following format:

$$P(x) = e^{A-Bx},$$

where A and B are parameters which are chosen to make the calculated probabilities match the observed spread of the leafhopper. The exponential functional form has certain advantages compared to alternative functional forms. First, for $A - Bx \geq 0$, it yields a value between 0 and 1,

[4] Any identified area too small to be sown sugarcane is filtered out.
[5] Leafhopper becomes ubiquitous almost immediately after reaching a new area, sometimes even accounting for 85% of specimens collected at an individual point. Therefore our predicting model does not take the intensity of the initial invasion into account.

which satisfies the requirement of a valid probability. Second, this equation allows for very high probabilities of spread over short distances, with much lower, but still non-negligible probabilities of spread over greater distances. The model is parameterized to reflect the speed at which the leafhopper is capable of spreading, unaided, in a year. Therefore, the values of A and B are chosen so that the probability of the leafhopper spreading to a new parcel half a mile away in a year is equal to 0.9 while the probability of the leafhopper spreading to a new parcel 10 miles away is 0.0005. These probabilities come from estimations by Dr. Jerry Cook at Sam Houston State University, an entomologist who studies leafhoppers in Texas.

The simulation begins with the leafhopper only present in its currently confirmed location. Then, for every other parcel in the dataset, the probability that the leafhopper spreads from the single occupied parcel is calculated, and the new parcel becomes occupied with that probability. This concludes the first simulated year. In the second year, the probability of spread is calculated from every parcel that is occupied to every parcel that is unoccupied, and the new parcel becomes occupied based on all of the calculated probabilities. This process is repeated for years three through twenty-five. Each twenty-five year cycle counts as a single iteration of the model, and the model is simulated for 10,000 iterations. Through the properties of Monte Carlo simulation, the frequency with which a parcel is occupied after N years in these 10,000 simulations should give a very good approximation of the actual probability that an individual parcel has the leafhopper present after N years. Figure 2 depicts the estimated likelihood of the leafhopper spreading throughout Louisiana at various points in time, focusing only on parishes with sugarcane.

[Insert Figure 2 Here]

Given the estimated probability of the leafhopper being present in any parcel at any point in time, expected aggregate losses of all n parcels within parish i is calculated as:

$$Loss_i = \sum_{j=1}^{n}[P_j * A_j * V * croploss] ,$$

where P_j is the probability that parcel j will have the leafhopper present at a certain year, A_j denotes the acreage of parcel j, and V is the average dollar value of each acre of sugarcane. In the estimation in this paper the value of V is set to be $2450, the approximate average value of a planted acre as part of a 4-year crop rotation from Salassi and Deliberto (2011). The value of $croploss$ is equal to 7.5% when only the leafhopper is present and 95% when both the leafhopper and the phytoplasm are present.

The estimates above should be interpreted as the conservative end of the leafhopper's spreading capabilities. The actual spread of the leafhopper is likely to be more aggressive than modeled. Two factors may contribute to this potential acceleration. First, the spread is assumed to be completely unaided. However, it is likely that human interaction with the leafhopper will lead to faster diffusion. For example, many sugarcane growers in Louisiana operate as members of cooperatives which share harvesting equipment. Equipment that travels from field to field over several parishes may carry the leafhopper with it and aid the spread. Additionally, it is assumed in the simulation that leafhoppers spread within sugarcane parcels only. If the leafhopper is also capable of spreading to other grasses between sugarcane parcels, the facilitated spread will accelerate the invasion as well. Therefore, the damages estimated at various points in time should be considered a best-case scenario. Actual crop, revenue, and job losses will likely be realized faster than indicated by the simulation results.

2. An input-output model of total economic impacts

The aggregated losses by parish only reflect the direct agricultural impacts of the leafhopper or leafhopper with the phytoplasm. To obtain total economic impacts, we use the

Impact analysis for Planning (IMPLAN) input-output model with year 2013 Louisiana data. IMPLAN is a combined software and data package produced by Minnesota IMPLAN Group (MIG). The IMPLAN model includes an input-output dollar flow table that traces the transaction of dollars between different sectors in the economy. Based on the input-output table, the IMPLAN model then generates economic multipliers that capture how a dollar in one sector is spent in other sectors. IMPLAN takes into account national and county level economic data and ultimately provides various multipliers that translate from a one dollar change in final production for a given sector to changes in output, personal income, employment, and taxes in the entire economy for every county/parish in the region and the nation.

For parishes growing sugarcane, the estimated direct agricultural impact is entered in IMPLAN as a reduction in the "Sugarcane and sugar beet farming" sector for that parish, and the multipliers are then used to calculate the total output, employment, and tax impacts for every parish in the state. The process is repeated for each sugarcane growing parish.[6] The total economic impact for each parish, whether sugarcane is grown there or not, is the aggregated change in total output resulting from all sugarcane growing parishes. The total impact in the state is obtained by aggregating the total economic impact across all parishes in the state. In addition, using industry specific multipliers, the total impact on output and employment can be broken down by affected industry. For example, a reduction in sugarcane farming in Rapides Parish can be translated into a change in real estate sales for Lafayette Parish. These breakdowns allow for an understanding of the societal distribution of impacts both geographically and by industry.

[6] Five parishes (Evangeline, East Baton Rouge, Jefferson, West Feliciana, and St. Charles) have some sugarcane growing within their borders, but because the parcels are part of farms in other parishes, the IMPLAN model does not recognize any sugarcane production within the parish. Losses within these parishes are re-assigned to neighboring parishes instead.

4. Results for the Red Streaked Leafhopper

The total economic impacts are estimated over a 25-year period, but only results for year 1, year 15 and year 25 are reported in this paper.[7] The direct impacts of the leafhopper after 15 and 25 years are listed by parish in Table 1. The first column under each year assumes that the leafhopper is spreading, but the phytoplasm is absent. The second column assumes the spread of both the leafhopper and the phytoplasm.[8] All estimates assume that no new action is taken by policymakers to stop the spread of the leafhopper.

[Insert Table 1 Here]

Even without the phytoplasm, farmers and farm owners stand to lose a total of over $16 million annually in the eighteen sugarcane growing parishes by year 15. Seven parishes stand to lose over $1 million each from the leafhopper alone. If the phytoplasm is present, losses are over $200 million in the eighteen parishes, with Pointe Coupee being the hardest hit parish. After 25 years, the total losses range from $75 million from the leafhopper to $956 million with the phytoplasm, with Iberia Parish alone accounting for over $136 million in losses.

[Insert Table 2 Here]

Table 2 lists the total economic impacts by parish for all parishes in Louisiana. After 15 years, the annual economic effects total almost $29 million from the leafhopper, and over $365 million with the phytoplasm. Pointe Coupee, the parish with the highest direct impact, also has the highest total impact at almost $9 million. After 25 years, the total economic effects rise to $132 million from the leafhopper and almost $1.7 billion with the phytoplasm. The most affected parish is St. Mary, which passes Iberia due to higher indirect and induced impacts. Comparisons

[7] The detailed results for all 25 years are available upon request from the authors.
[8] With the initial leafhopper presence occurring in Rapides parish, every parcel in Rapides has a 100% probability of infection after 15 years. Therefore, the direct impacts for Rapides do not change from 15 to 25 years.

between total economic impacts from Table 2 and direct economic impacts from Table 1 reveal that total economic impacts are about 1.8 times larger than their direct counterparts. Therefore examining only the direct impacts of the invasion would capture merely 57% of the true economic impacts.

While the largest portion of economic impacts falls in the 23 parishes growing sugarcane, the parishes with no sugarcane industry lose almost $2.4 million annually at the 25 year mark from the leafhopper, and over $30 million annually with the phytoplasm. These parishes are not directly impacted, but they still suffer indirect and induced impacts. Thus estimating the direct economic impacts instead of the total economic impact can result in misleading estimates, and impacts to individuals and areas outside the sugarcane industry will be ignored. From the policymaking perspective, focusing on direct economic impacts only may result in insufficient prevention and control actions from the authorities and interest groups.

Another way to examine the impacts of the invasive species is to translate total impacts into impacts on tax revenue and employment. Table 3 summarizes these impacts of the leafhopper invasion. State and local governments would lose $73 thousand annually after 15 years of the leafhopper spreading, while federal revenues would be reduced by $440 thousand. After 25 years, these numbers increase to $683 thousand and $3.3 million respectively. Given the fact that the leafhopper is already present in Louisiana and its spread is almost guaranteed without a response, these foregone tax revenues from a single year could justify a multimillion dollar response from various levels of government. Note that cumulative effects would be significantly larger and would depend on how rapidly the actual spread of the leafhopper occurs.

[Insert Table 3 Here]

If the leafhopper spreads along with the phytoplasm, state and local tax revenues would be reduced annually by almost $1 million after 15 years and $8.6 million after 25 years. Federal tax receipts would be down by $5.5 million after 15 years and over $42.5 million annually after 25 years.

Employment impacts from the leafhopper's spread range from 127 lost jobs from just the leafhopper in year 15 to 10,397 lost jobs from the leafhopper and phytoplasm in year 25. With current employment in Louisiana at approximately 1,960,000, losing 1608 jobs would increase unemployment by almost a tenth of a percentage point, while losing 10,397 jobs would increase unemployment by over half a percentage point.

Both total economic impacts and employment impacts can be broken down by affected industry. These breakdowns are reported for year 25 in Table 4. Unsurprisingly, sugarcane production is the most affected industry by both employment and output. Other highly affected industries are, perhaps, less expected. The third most affected industry by employment is real estate, and the fifth most affected is food service and drinking places. Petroleum refineries and banks are ranked second and third by output. Clearly, the impacts of the leafhopper extend beyond agricultural industries.

[Insert Table 4 Here]

In addition to the impacts calculated here, a spread of both the leafhopper and phytoplasm would likely lead to a small but not insignificant increase in US sugar prices, which in turn could affect the prices of corn syrup, artificial sweeteners, and other related products. While it is beyond the scope of this paper to estimate all of these effects, recognizing them does help in understanding the broad and far-reaching impacts that the invasion might have.

This paper looks only at the impacts of the leafhopper on Louisiana sugarcane. Now that it is established in the continental United States, the leafhopper also poses a threat to the sugarcane industry in Texas and the sugarcane industry in Florida, which produces even more sugarcane than Louisiana (United States Department of Agriculture- Economic Research Service, 2014). The establishment of the leafhopper in the western hemisphere is also of concern to Brazil, whose vast sugarcane harvests are used in their successful ethanol program.

5. Discussion—benefits of early intervention

Rejmanek and Pitcairn (2002) point out that early detection and intervention can be the most effect way to control the spread of invasive species. Actually, for certain species, complete eradication turns to be impossible after the intensity of invasive species reaches a certain level. Figure 3, adopted from Rejmanek and Pitcairn (2002), shows the estimated relationship between the probability of successfully eradicating invasive species, average number of work hours needed, and the infestation area. As expected, the higher the infestation area, the less likely for eradication is to succeed. Almost immediately after the initial invasion, the probability of success drops dramatically from around 90% to about 45%. The amount of effort needed for eradication is below 10,000 hours when infestation is relatively low, but goes up dramatically when the intensity of the infestation increases.

In addition, from the economic perspective, early intervention and detection also allows for substantially saving on future economics losses. To further examine the benefit of early intervention, we summarize the direct and total economic impacts of leafhopper in years 1, 15 and 25 in Table 5. The direct impacts in year 1 range from about $0.1 million without the phytoplasm to about $1.5 million with the phytoplasm in year 1. Without adequate control, the leafhopper could cost all parishes in Louisiana as much as $75 million in lost sugarcane production without the phytoplasm or almost $1 billion with the phytoplasm 25 years later. The contrast between the years reported in terms of total economic impacts is even more significant. Without the phytoplasm, the total impacts in year 1 are only $211 thousand, while the total impacts increase to about $29 million in year 15 and $132 million in year 25. If the phytoplasm is present, the total impacts in year 1 are about $2.7 million, and the figure increases to $365 million and $1.7 billion respectively in years 15 and 25.

6. Conclusion

The economic impacts of invasive species have been estimated in the billions or trillions of dollars annually and still growing, but response and prevention efforts are orders of magnitude smaller (Pimentel, et al., 2001). This may be because i) the true economic impacts of an invasive species are often underestimated because indirect and induced impacts are usually ignored in previous estimates, ii) the costs of invasive species are often only calculated after the invasion has occurred and response or prevention efforts are much less effective by then, and iii) the costs of the invasive species are assumed to fall on a limited group of industries or individuals that are directly impacted. This paper introduces a more comprehensive approach to estimating the total economic impacts of an invasive species prior to the invasion. By predicting the invasion through simulations, estimates of direct impacts can be obtained and indirect and induced impacts can be estimated using an input-output model. The accurate estimates of the total economic impacts are essential for a policymaker to make effective response decisions. In addition, by examining the breakdown of the impacts across society and industries, appropriate support can be garnered to craft a response.

To illustrate the approach, the invasion of the Red Streaked Leafhopper is considered. A leafhopper invasion model is built and Monte Carlo simulation is used to predict the spread across the eighteen parishes in Louisiana that grow sugarcane. The IMPLAN input-output model is then used to calculate the total economic impacts at various geographic levels and in different dimensions. The estimates predict that total annual impacts can be as high as $75 million from the leafhopper or as high as $956 million from the leafhopper carrying a specific phytoplasm after 25 years. State and local governments would lose $683,000 annually while federal revenues would be reduced by $3.3 million after 25 years. Employment effects from the leafhopper's spread range from 821 lost jobs with just the leafhopper to 10,397 lost jobs with the leafhopper and phytoplasm at 25 years, an almost 0.1% increase in Louisiana's unemployment at current employment levels. These geographic, governmental, and industrial breakdowns highlight the broad societal distribution of the leafhopper's impacts.

The total economic impacts and their breakdown enables future research and discussion on developing optimal responses to an invasion, funding responses proportionally by geographic or industrial impacts, and estimating tertiary effects on equilibrium prices and economic losses resulting from the reduced supply of the directly affected industry. Fully understanding the myriad impacts of an invasion and optimizing responses should allow policy makers to greatly mitigate the potential negative impacts of invasive species.

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Figure 1

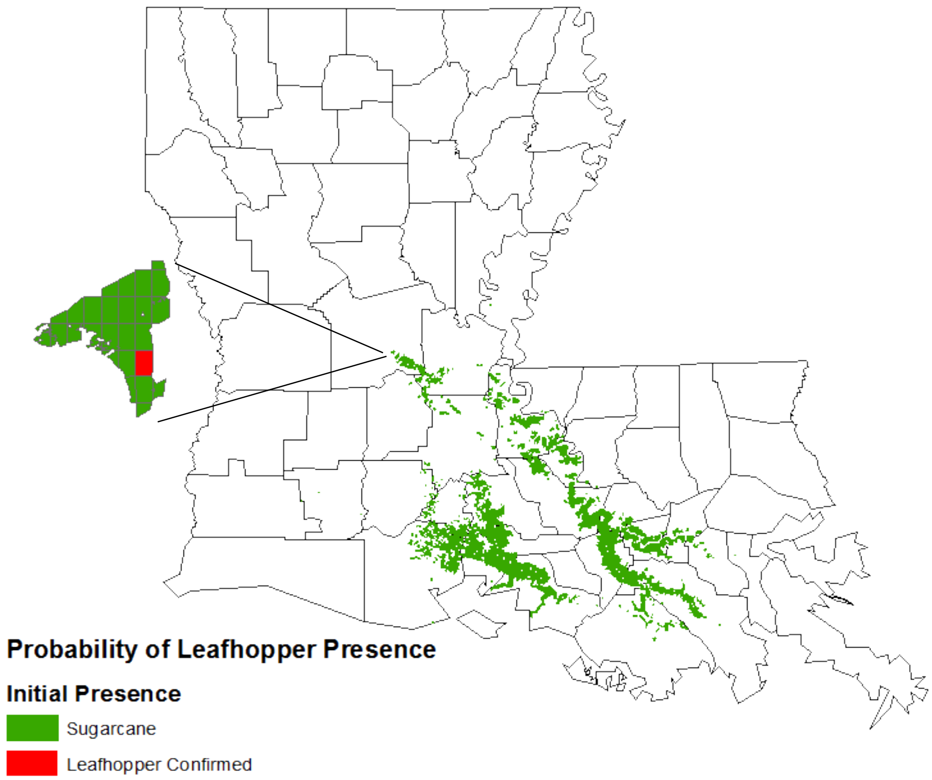

Probability of Leafhopper Presence
Initial Presence
Sugarcane
Leafhopper Confirmed

Figure 2

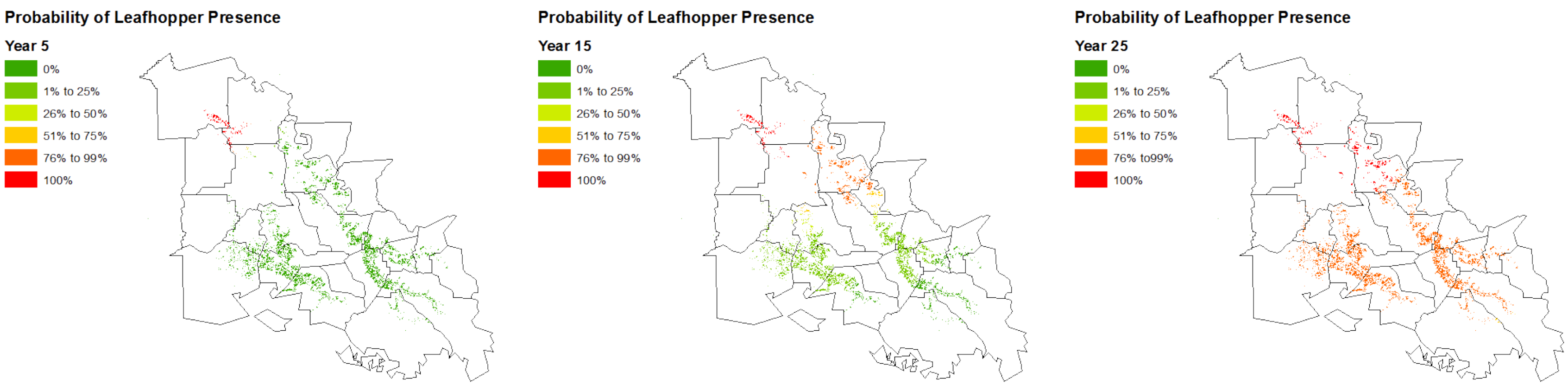
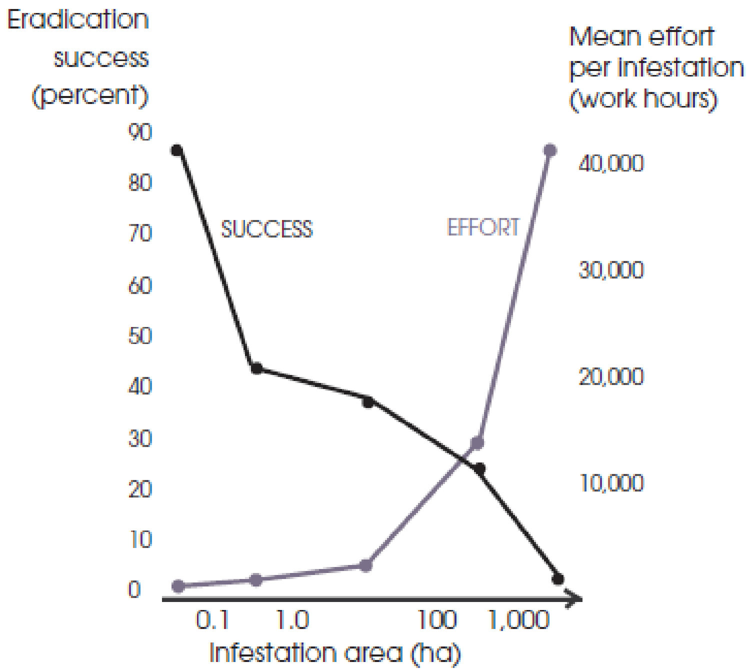

Probability of Leafhopper Presence
Year 5
0%
1% to 25%
26% to 50%
51% to 75%
76% to 99%
100%
Probability of Leafhopper Presence
Year 15
0%
1% to 25%
26% to 50%
51% to 75%
76% to 99%
100%
Probability of Leafhopper Presence
Year 25
0%
1% to 25%
26% to 50%
51% to 75%
76% to99%
100%

Figure 3



Source: Rejmanek, M., Pitcairn, M.J. (2002). When is eradication of exotic pest plants a realistic goral? In C. R. Weitc, Turning the tide: the eradication of invasive species (pp. 249-253). IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland, Cambridge.

Note: Based on data for eradication projects of 18 noxious week species and 53 independent infestations in California.

Table 1: Direct impacts by parish after 15 and 25 years

	Year 15		Year 25	
Parish	Leafhopper	Leafhopper + Phytoplasm	Leafhopper	Leafhopper + Phytoplasm
Acadia	5,163	65,395	291,733	3,695,281
Ascension	27,145	343,842	2,621,344	33,203,693
Assumption	18,407	233,158	7,998,012	101,308,149
Avoyelles	1,471,743	18,642,073	1,473,619	18,665,846
Iberia	489,007	6,194,087	10,746,888	136,127,247
Iberville	1,950,030	24,700,374	6,994,713	88,599,698
Lafayette	106,823	1,353,094	1,538,145	19,483,165
Lafourche	30	375	4,895,403	62,008,436
Pointe Coupee	6,095,530	77,210,049	6,581,998	83,371,979
Rapides	1,555,260	19,699,960	1,555,260	19,699,960
St. James	2,158	27,341	4,509,075	57,114,944
St. John the Baptist	1	17	1,583,866	20,062,305
St. Landry	1,037,002	13,135,365	1,207,199	15,291,182
St. Martin	1,362,344	17,256,356	5,268,350	66,732,432
St. Mary	13,096	165,878	8,391,959	106,298,148
Terrebonne	0	0	1,715,384	21,728,201
Vermilion	76,043	963,213	5,430,584	68,787,401
West Baton Rouge	1,932,048	24,472,609	2,688,704	34,056,923
Total	16,141,830	204,463,185	75,492,236	956,234,992

Table 2: Total impacts by parish after 15 and 25 years

	Year 15				Year 25	
Parish	Leafhopper	Leafhopper + Phytoplasm		Parish	Leafhopper	Leafhopper + Phytoplasm
Acadia	28,700	363,529		Acadia	602,152	7,627,258
Allen	18,378	232,783		Allen	27,309	345,910
Ascension	782,006	9,905,405		Ascension	6,703,103	84,905,966
Assumption	29,067	368,182		Assumption	10,211,049	129,339,951
Avoyelles	2,417,511	30,621,802		Avoyelles	2,437,835	30,879,250
Beauregard	2,210	27,990		Beauregard	8,197	103,832
Bienville	432	5,473		Bienville	1,203	15,240
Bossier	20,645	261,503		Bossier	38,041	481,859
Caddo	84,949	1,076,024		Caddo	162,439	2,057,559
Calcasieu	78,795	998,068		Calcasieu	410,549	5,200,287
Caldwell	2,216	28,071		Caldwell	4,815	60,990
Cameron	1,878	23,791		Cameron	10,884	137,861
Catahoula	5,197	65,830		Catahoula	9,383	118,855
Claiborne	340	4,309		Claiborne	957	12,119
Concordia	10,546	133,578		Concordia	16,127	204,272
De Soto	6,658	84,338		De Soto	12,806	162,212
East Baton Rouge	1,598,696	20,250,155		East Baton Rouge	3,524,670	44,645,814
East Carroll	260	3,289		East Carroll	880	11,141
East Feliciana	9,945	125,969		East Feliciana	31,384	397,537
Evangeline	118,027	1,495,010		Evangeline	158,005	2,001,399
Franklin	1,137	14,407		Franklin	3,199	40,523
Grant	7,346	93,048		Grant	10,176	128,899
Iberia	901,745	11,422,101		Iberia	16,274,656	206,145,640
Iberville	3,165,322	40,094,077		Iberville	10,857,396	137,527,011
Jackson	343	4,339		Jackson	964	12,214
Jefferson	71,050	899,962		Jefferson	742,887	9,409,897
Jefferson Davis	8,223	104,159		Jefferson Davis	210,532	2,666,741
La Salle	26,787	339,298		La Salle	34,622	438,547
Lafayette	646,403	8,187,774		Lafayette	5,500,482	69,672,772
Lafourche	43,265	548,027		Lafourche	7,582,247	96,041,791
Lincoln	1,022	12,951		Lincoln	2,756	34,903
Livingston	27,411	347,209		Livingston	96,037	1,216,465

Table 2 (cont.): Total impacts by parish after 15 and 25 years

	Year 15				Year 25	
Parish	Leafhopper	Leafhopper + Phytoplasm		Parish	Leafhopper	Leafhopper + Phytoplasm
Madison	202	2,553		Madison	803	10,166
Morehouse	785	9,946		Morehouse	2,614	33,105
Natchitoches	22,544	285,558		Natchitoches	32,681	413,955
Orleans	123,251	1,561,184		Orleans	865,877	10,967,773
Ouachita	17,074	216,271		Ouachita	46,759	592,283
Plaquemines	5,846	74,043		Plaquemines	35,767	453,048
Pointe Coupee	8,822,740	111,754,711		Pointe Coupee	9,690,180	122,742,282
Rapides	2,490,430	31,545,444		Rapides	2,569,713	32,549,693
Red River	7,281	92,221		Red River	10,465	132,558
Richland	543	6,875		Richland	1,801	22,814
Sabine	867	10,988		Sabine	1,992	25,228
St. Bernard	3,070	38,880		St. Bernard	40,964	518,882
St. Charles	177,262	2,245,313		St. Charles	3,219,477	40,780,043
St. Helena	869	11,010		St. Helena	3,408	43,169
St. James	132,924	1,683,704		St. James	7,586,829	96,099,830
St. John the Baptist	52,113	660,103		St. John the Baptist	3,992,097	50,566,567
St. Landry	1,919,232	24,310,270		St. Landry	2,987,991	37,847,881
St. Martin	57,445	727,633		St. Martin	860,157	10,895,328
St. Mary	1,752,059	22,192,751		St. Mary	17,949,205	227,356,603
St. Tammany	16,224	205,505		St. Tammany	90,250	1,143,161
Tangipahoa	21,048	266,611		Tangipahoa	102,964	1,304,205
Tensas	1,017	12,877		Tensas	3,119	39,507
Terrebonne	21,520	272,585		Terrebonne	3,338,539	42,288,160
Union	281	3,563		Union	1,047	13,256
Vermilion	214,677	2,719,240		Vermilion	9,263,232	117,334,273
Vernon	4,510	57,130		Vernon	6,623	83,893
Washington	6,448	81,679		Washington	35,058	444,064
Webster	2,135	27,040		Webster	6,102	77,286
West Baton Rouge	3,077,337	38,979,601		West Baton Rouge	4,642,227	58,801,542
West Carroll	286	3,629		West Carroll	1,120	14,185
West Feliciana	53,750	680,834		West Feliciana	291,699	3,694,854
Winn	7,765	98,358		Winn	11,776	149,159
Total Economic Impact	28,866,167	365,638,112		**Total Economic Impact**	132,477,218	1,678,044,763

Table 3: Tax and Employment Impacts

Leafhopper		
	Year 15	Year 25
Direct Impacts	16,141,830	75,492,236
Total Impacts	28,866,167	132,477,218
Local and State Tax Impacts	73,445	683,593
Federal Tax Impacts	440,753	3,358,774
Employment Impacts	127 Jobs	821 Jobs

Leafhopper + Phytoplasm		
	Year 15	Year 25
Direct Impacts	204,463,185	956,234,992
Total Impacts	365,638,112	1,678,044,763
Local and State Tax Impacts	930,299	8,658,844
Federal Tax Impacts	5,582,877	42,544,468
Employment Impacts	1608 Jobs	10,397 Jobs

Table 4: Top ten affected industries by employment and output (Year 25)

Employment Impacts			Output Impacts		
Industry	Leafhopper	Leafhopper and Phytoplasm	Industry	Leafhopper	Leafhopper and Phytoplasm
Sugarcane and sugar beet farming	-1,376	-17,431	Sugarcane and sugar beet farming	-78,613,854	-995,775,484
Support activities for agriculture and forestry	-91	-1,157	Petroleum refineries	-9,397,308	-119,032,570
Real estate establishments	-34	-433	Monetary authorities and depository credit intermediation activities	-4,794,959	-60,736,153
Maintenance and repair construction of nonresidential structures	-25	-310	Real estate establishments	-4,499,414	-56,992,576
Food services and drinking places	-23	-294	Pesticide and other agricultural chemical manufacturing	-3,017,639	-38,223,432
Monetary authorities and depository credit intermediation activities	-16	-208	Imputed rental activity for owner-occupied dwellings	-2,690,438	-34,078,883
Wholesale trade businesses	-10	-132	Maintenance and repair construction of nonresidential structures	-2,572,953	-32,590,733
Offices of physicians, dentists, and other health practitioners	-9	-117	Support activities for agriculture and forestry	-2,496,413	-31,621,231
Private hospitals	-9	-114	Fertilizer manufacturing	-2,358,274	-29,871,472
Transport by truck	-7	-85	Electric power generation, transmission, and distribution	-2,072,233	-26,248,289

Table 5: The benefits of early intervention

	Direct Impacts	
	Leafhopper	Leafhopper + Phytoplasm
Year 1	116,614	1,477,111
Year 15	16,141,830	204,463,185
Year 25	75,492,236	956,234,992

	Total Impacts	
	Leafhopper	Leafhopper + Phytoplasm
Year 1	211,513	2,679,159
Year 15	28,866,167	365,638,112
Year 25	132,477,218	1,678,044,763