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Rapid Response Lowers Eradication Costs of Invasive Species: Evidence from Florida

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Introduction

Of the approximately 50,000 nonnative species that have been introduced into the United States, nearly 4,600 of them are classified as harmful invasive species (Pimentel et al., 2000; Corn et al., 2002). These organisms have caused major economic and environmental damages to the tune of $120 billion per year (Pimentel, Zuniga, and Robinson, 2005). Invasive species have also been found to negatively impact human well-being (Jones, 2017) and to induce trophic cascades (Walsh, Carpenter, and Vander Zanden, 2016). The annual toll inflicted by invasive species to U.S. agriculture is significant: Pest insects cause an estimated $13 billion in crop losses on top of the $1.2 billion farmers spend in insecticides, while weeds cause an estimated reduction of 12% in crop yields ($33 billion in production losses) despite $3 billion spent on herbicides each year (Pimentel et al., 2000). Similarly, invasive forest pests cause nearly $5 billion in damages and losses throughout the United States, including $2.25 billion in costs to governments, $2.55 billion in costs to homeowners, and $152 million in losses to timber producers (Aukema et al., 2011).

In the past 40 years, biological invaders and the risk associated with them have increased mainly due to rapid human population growth and mobility coupled with radical alteration of ecosystems across the globe. In addition, more goods and materials are being traded between nations than ever before, creating opportunities for unintentional introductions (Perrings et al., 2002; Evans, 2003; Alvarez, 2016). Recent analyses on invasion threats indicate that the level of damages to agriculture worldwide is likely to increase, with major food-producing nations such as the United States, Canada, China, Argentina, Australia, and South Africa among the most threatened nations (Paini et al., 2016).

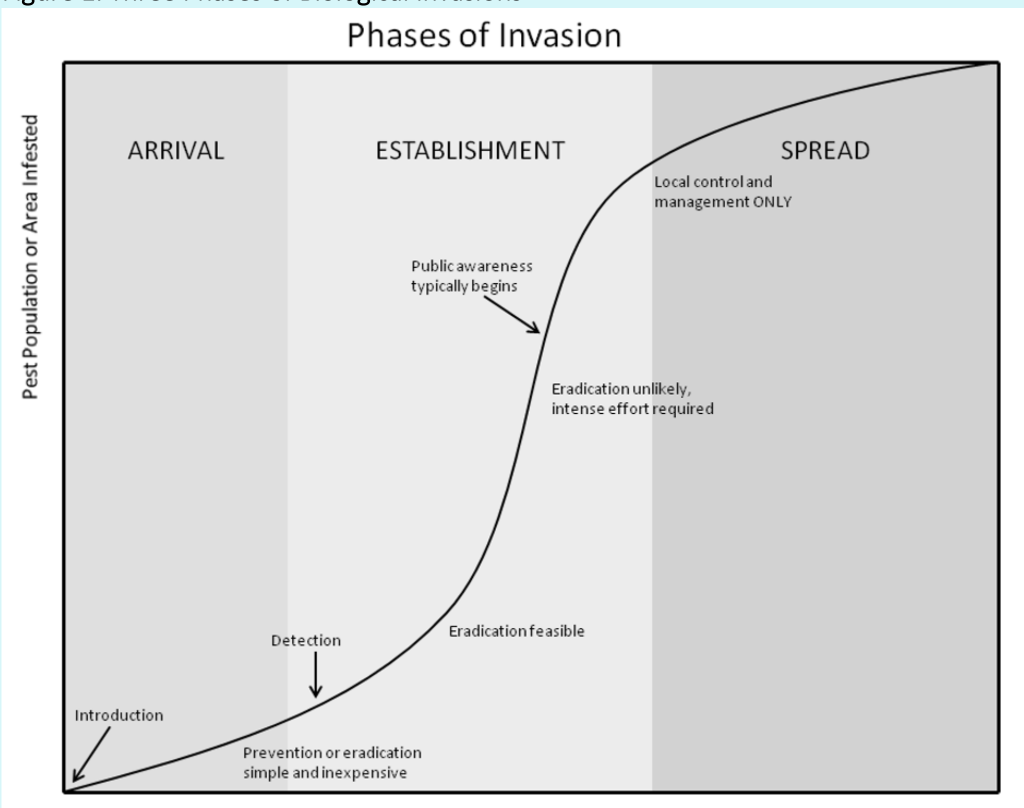
While government agencies have developed guidance documents with specific recommendations for early detection and rapid response (National Invasive Species Council, 2016; U.S. Department of the Interior, 2016) and some international agreements mention invasive species (Lodge et al., 2016), there are no clear science-based national policies to deal with invasive species in the United States (Mhina et al., 2016). Instead, response efforts have been established on a case-by-case basis, and policy makers and stakeholders play a big role in deciding which invasions are targeted for control or eradication and when those efforts are to take place. Here we offer evidence that the economic costs associated with invasive species is in large part determined by the response time between arrival of a pest and the beginning of eradication or control efforts.

To make our case, we first discuss the three phases of a biological invasion and the main strategies—in terms of response time—that policy makers have followed to deal with the threat. We also present a review of representative biological invasions that have affected Florida's agriculture industry, categorized by the invasion phase in which eradication efforts were implemented. Finally, we discuss policy implications and recommendations.

Phases of Biological Invasions

Biological invasions have three major phases: arrival, establishment, and spread (Liebhold and Tobin, 2008; Alvarez, 2016; Lodge et al., 2016; Figure 1). The *arrival* or introduction phase generally involves just a few individuals that have hitched a ride on luggage, packing materials, or plant and animal tissue or have been brought intentionally for noncommercial uses such as preparation of meals. A period of relatively slow growth in which the invader's population is below detection thresholds follows. At such low population levels, individual invaders have difficulty finding mating partners, and simple and inexpensive eradication efforts can effectively stop the invasion. Some invasions will simply come to a natural end as individuals are unable to find mating partners or die in the presence of an adverse environment. However, it is unlikely that new invaders will be detected at the arrival phase if there are no surveillance systems with technically trained personnel capable of promptly identifying these invaders. Customs and border officials, along with agricultural pest surveillance systems are critical to detect and eliminate invasive species at this phase.

Figure 1. Three Phases of Biological Invasions



Source: Alvarez (2016)

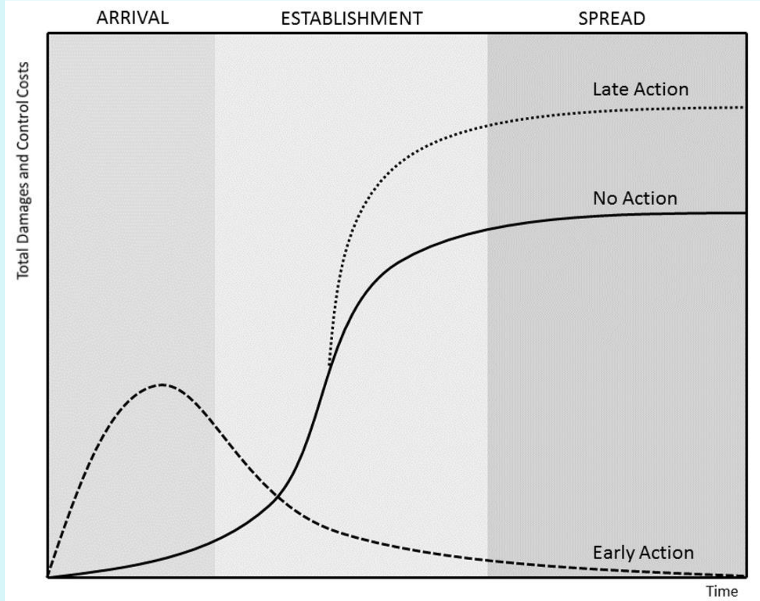
In the *establishment* phase, the invader's population grows to the point where detection will happen even without the presence of a surveillance system. Even at this threshold, the invader's population is too small to garner significant public awareness; without an aggressive policy in place, the invasion is generally allowed to continue. The invader's population then starts growing much faster as individuals can easily find mates and food. A second threshold is reached, and public awareness and concern about the invasion grows. By this time, the invader is typically well established in the new range and eradication is unlikely, even if costly and aggressive efforts are undertaken.

In the *spread* phase, the invader's population reaches its maximum level or carrying capacity, as the invaders populate all suitable habitat in the area. The invaded area then becomes the source of new invasions as the crowded invaders start moving to new areas, usually with the help of unsuspecting humans.

Strategies Used to Address Invasive Species

There are three main strategies that policy makers can follow when faced with a biological invasion: take no action at all; act late in the invasion; or take preventive actions and act early in the arrival phase (Gutrich, VanGelder, and Loope, 2006). Figure 2 summarizes these strategies and their associated costs.

Figure 2. Policy Strategies and Associated Damages and Control Costs of Invasive Species



No Action

In the arrival phase, new invaders are unlikely to cause significant losses. Hence it may be tempting to do nothing when a new biological invasion is detected and use public resources to address other issues. However, costs will increase as the invader's population grows and the damage it causes becomes evident. Costs in a given area will eventually stop growing once the invading pest is completely established, but the industries it affects will be devastated to the point where they either go out of business or are operating with large costs to control the pest at a localized level.

Late Action

Policy makers may decide to do nothing during the arrival phase but will attempt to control the invader once the population grows and economic damage becomes evident. However, at this point the pest will be well established and eradication is unlikely. Costs will grow as the invader's population grows and will be higher than in the "no action" scenario as efforts to control the pest at a regional level must be maintained indefinitely, even though these efforts are unlikely to be effective.

Early Action

If a surveillance program for detecting new invaders exists, policy makers will become aware of biological invasions early in the arrival phase, before the public and stakeholders begin to notice the invaders. An aggressive quarantine and eradication effort at this early stage is costly and may be unpopular but has a high chance of being effective. Once the budding invasion is eliminated, there will be no further control costs or losses in production.

Invasive Species in Florida Agriculture

Florida's production agriculture is one of the most diverse in the United States and includes fruits, vegetables, row crops, ornamental plants, and all forms of commercial livestock. Florida's 47,740 farms cover 9.5 million acres and produce sales with an annual farm-gate value $7.7 billion (U.S. Department of Agriculture, 2014).

Florida, California, and Texas are the only U.S. states in the high-risk cluster for biological invasions (Borchert, Brightwell, and Magarey, 2013), and Florida has recently experienced several biological invasions with negative consequences for agriculture. The extent of negative consequences is largely a function of the phase of invasion in which control and eradication efforts began in earnest, and can be categorized into those where eradication efforts began at the *arrival* phase, at the *establishment* phase, or at the *spread* phase.

Group 1: Control Efforts Begin at the Arrival Phase

Oriental Fruit Fly

Oriental Fruit Fly (OFF) was detected in Miami-Dade County on August 2015 and was eradicated by March 2016 after an aggressive collaborative effort. The OFF female lays its eggs in fruit and vegetables, and when the eggs hatch the larvae eat the product from the inside, making it unfit for consumption. More than 400 fruits and vegetables are potential OFF hosts, including all the fruits and vegetables grown commercially in South Florida. Due to their damage potential, many nations, including the United States, have strong restrictions on agricultural imports from areas where OFF are present.

The OFF outbreak in Miami-Dade was detected promptly due to the fruit-fly surveillance and trapping program. The eradication program involved the male annihilation technique—in which pheromone-laden pesticide was sprayed on trees and poles—and aerial pesticide sprays. Even though the OFF outbreak in Miami-Dade was detected early and the eradication effort was effective, fruit and vegetable growers in the area lost an estimated $10 million and government agencies spent $3.5 million. The estimated economic impact of these losses is $27 million, with a loss of 334 jobs (Alvarez, Evans, and Hodges, 2016).

Without a surveillance program and an aggressive eradication effort, it is very likely that OFF would have become established in Miami-Dade's agricultural production areas. The annual agricultural value at risk in Miami-Dade alone exceeds $592 million. Between trade restrictions and spoiled produce, losses from establishment of the OFF could have be catastrophic.

New World Screwworm

New World Screwworm (NWS) was detected in the Florida Keys in July 2016, infecting endangered male Key deer, but was not officially identified until September 2016 after several deer had to be euthanized due to the severity of their infestations (Delgado, Hennessey, and Hsi, 2016). NWS is a fly larva that feeds on the living tissue of warm-blooded animals. The females lay their eggs on or near an open wound or in the animal's nose, mouth, or ears. The eggs hatch within a day and the larvae feed on the animal's tissue for 5–7 days before they drop to the ground to pupate and then emerge as adults. Infested, untreated animals usually die within 15 days. NWS is currently established in South America and several Caribbean nations.

Prior to the 1950s, NWS was present throughout the U.S. Southeast and Southwest, as well as Mexico and Central America. In 1957, the USDA began releasing sterile male flies throughout the United States, and by 1966 screwworm was eradicated. The Sterile Insect Technique involves sterilizing male flies using irradiation. Large numbers of sterile males are then released, and when they mate with wild females their eggs either will not hatch or will die shortly after hatching. To ensure that NWS would not return to the country via trade with Mexico, the USDA also used this technique to eradicate NWS in Mexico and Central America. A breeding facility for sterile males was constructed in Panama, and millions of sterile males are released every year in the Isthmus of Panama to prevent the spread of NWS from South America. Eradication of NWS in Mexico and Central America was achieved in the 1990s.

Spread of NWS to mainland Florida could prove catastrophic for livestock industries. The USDA reports that in the 1930s, NWS was "causing livestock producers to lose millions of dollars annually" (U.S. Department of Agriculture, 2014). Because of the outbreak of NWS in Florida, several states and nations placed restrictions on imports of animals from Florida, including the U.S. states of Georgia and Utah as well as Lebanon, Jordan, Cuba, and Australia. Full eradication was achieved in March 2017 after more than 154 million sterile flies were released and 17,000 animals were inspected using 700 hours of surveillance (U.S. Department of Agriculture, 2017), at an expense of $2 million in eradication costs (unpublished cost data).

Group 2: Control Efforts Begin at the Establishment Phase

Conehead Termites

Conehead termites, a highly social termite species native to tropical areas in the Americas, were first detected in 2001 by a pest control technician working in Dania Beach near the Ft. Lauderdale airport. An initial eradication campaign was deemed successful and discontinued. However, some colonies survived, and several colonies were detected again in 2012 around the original infested area.

In their native range, conehead termites are a very destructive structural pest due in part to their adaptability to the urban environment. For instance, several cities in Brazil and Argentina experience infestations of conehead termites in more than 60% of surveyed structures (Fontes and Milano, 2002). The Florida State Department of Agriculture has established a small but aggressive eradication effort that relies on a mix of chemical termiticide treatments and physical destruction and removal of termite colonies, and has spent upwards of $1 million in these efforts since 2012. While efforts have been successful at preventing damage to structures, colonies persist in wooded areas and poorly tended yards.

In the absence of an eradication and control program, conehead termites would cost homeowners $9.9 million and invade an area of 561 acres by 2024 (Alvarez, 2016). In recent months, a second outbreak of conehead termites has been detected in Pompano Beach, next to a landfill site located 16 miles north of the original outbreak location. The second outbreak was likely caused by incidental transportation of infested wood materials from Dania Beach, and its potential costs were not included in the economic assessment. While control efforts are ongoing, it is unlikely that full eradication will be achieved soon.

Giant African Land Snail

The current outbreak of Giant African Land Snails (GALS) was detected in South Florida in 2011. A previous outbreak, in the 1960s, was eradicated after a 10-year effort. GALS is a voracious generalist eater that can consume every type of agricultural crop grown in Florida. If fruits or vegetables are not available, the snails will eat a wide variety of ornamental plants, tree bark, and even paint and stucco on houses. Besides their threat to agriculture and structures, GALS can also carry a parasitic nematode that can cause meningitis in humans (Smith et al., 2015). Florida's eradication effort consists on the physical removal of snails from infested areas and the use of poisonous snail baits, costing state and federal agencies more than $15 million since 2011. While eradication has not been achieved yet, it is believed that continued efforts have been effective and complete eradication is on the horizon.

Group 3: Control Efforts Begin at the Spread Phase

Citrus Greening

Citrus greening disease, or Huanglongbing (HLB), is a bacterial disease vectored by a small insect, the Asian citrus psyllid. The citrus psyllid was first detected in Florida in 1998 and was considered a minor pest at the time. Without a concerted eradication effort, the psyllid spread rapidly and was present throughout the state by 2004, when the first cases of HLB in Florida were identified. Since the psyllid vector was well established throughout Florida, the HLB bacteria spread quickly throughout Florida's commercial citrus producing regions.

Efforts to control HLB began in earnest once the devastation it caused became evident. However, millions of dollars in research and collaborative partnerships between industry and the government have not stopped the decline of the citrus industry. In the 2003–2004 production year, before the first cases of HLB were identified, Florida produced 291.8 million boxes of citrus. By the 2014–2015 production season, Florida was only producing 112.6 million boxes of citrus. Losses in production due to HLB between the 2006–2007 and 2010–2011 production seasons were estimated at $1.7 billion, or $340 million per year (Hodges and Spreen, 2012). Losses continue to mount as citrus producers today use more pesticides and nutrient sprays to produce lower yields, with production costs per acre nearly $1,000 higher than they were in 2003 (Alvarez, Evans, and Hodges, 2016).

Laurel Wilt

Laurel wilt is a fungal disease that is vectored by the Asian ambrosia beetle. It affects all trees in the laurel family, including commercial varieties of avocado, and results in the rapid death of infected trees. The disease was first discovered near Savannah, Georgia, in 2002 and quickly spread through redbay trees in coastal forests. Laurel wilt has slowly made its way south, and in 2011 it was detected on swampbay trees in Miami-Dade County, where Florida's avocado industry is located.

Since laurel wilt infection results in tree death in more than 92% of cases, it has the potential to completely devastate the Florida avocado industry, which has an annual wholesale value of $30 million. Currently there are no effective treatments for laurel wilt. A complete loss of Florida's avocado industry would result in an annual economic impact of $54.2 million and the loss of 546 jobs (Evans et al., 2010). To date, there is no concerted effort to eradicate laurel wilt from the United States.

Policy Recommendations

Eradication of invasive agricultural pests is possible, but it requires a mix of rapid detection, forward-looking risk assessments, effective control methods, and aggressive action. An early warning system for rapid detection and identification of invasive pests that includes insect and spore traps, field surveillance, systematic customs inspections, and other means is the first step to minimize damage from biological invasions (Holden, Nyrop, and Ellner, 2016). Such systems give policy makers a leg up on biological invaders, and without them early action is not even an option. Investment in research and development can facilitate production of more effective and inexpensive monitoring systems. Similarly, advances in augmented reality and artificial intelligence can assist field staff to rapidly and inexpensively detect and identify new invaders. Surveillance systems are some of the most inexpensive measures that governments can take to tackle biological invasions.

Once a new invader is detected and identified, the next question for policy makers is how aggressively, if at all, the new invader should be targeted for eradication or control. Only a fraction of the new organisms that come to our shores will cause havoc, and it is important to manage public resources efficiently and target only the most dangerous invaders. Thus, policy makers face two conflicting options: act quickly in order to prevent potentially catastrophic damage or wait and see before starting an irreversible, costly, and unnecessary eradication program. Which of these is the better choice depends on how fast the invader can spread and how damaging it can be. For fast-spreading pests with high destructive potential, the decision to act quickly is best, while for slow spreading pests with low destructive potential, the best decision is to wait and see (Sims, Finoff, and Shogren, 2016). But to separate harmless and even beneficial organisms from the dangerous ones, policy makers must invest in forward-looking risk assessments that help identify species with high reproductive and damage potential (Keller, Frang, and Lodge, 2008; Lodge et al., 2016). Such assessments can then inform a prioritization scheme to identify which new species to target for immediate eradication and which to allow into the area. Without this information, policy makers may tend to default to a wait-and-see approach, as was the case with our examples from Florida: The two invaders in Group 1 (OFF and NWS) were widely known for their destructive and reproductive potential and were targeted for immediate eradication, while little was known of the potential for damage and spread of the invaders in Groups 2 and 3, where authorities initially decided to wait and see.

Once a new invader is detected, identified, and targeted for eradication, the next question to be answered is which method will be used in the eradication effort. Eradication of invasive insects, such as OFF or NWS, has been made possible by the development of narrow-target techniques, which disrupt the breeding cycle of the target population. Besides having high efficacy, narrow-target eradication techniques do not rely on spraying wide-spectrum pesticides on large areas, are unlikely to affect native organisms, and are less likely to result in public opposition. Development of effective narrow-target techniques for the most dangerous agricultural invasive pests can benefit multiple nations and should be considered as an area of increased investment for governments and supra-national organizations. Collaborative partnerships between governments, researchers, and stakeholders can also facilitate successful eradication outcomes.

An effective eradication technique by itself will not bring about eradication of an invasive pest without aggressive and concerted action by policy makers and stakeholders. Implementing aggressive quarantine protocols is of vital importance to prevent the accidental movement of materials infested with the invasive pest and the establishment of new outbreak areas. Eliminating and treating potential food sources for the invading pest, even when they will result in costly losses to stakeholders, is necessary to break the invader's life cycle. Persistent and increased surveillance in the outbreak locations for the duration of several life cycles are also necessary to ensure that the invading population is eliminated.

Eradicating invasive pests requires implementation of a complex decision-making process and a concerted, aggressive effort in the field. But above all, time is of the essence. Addressing tomorrow's biological invasions must necessarily begin today with smart public investments in surveillance systems, forward-looking risk assessments, and effective narrow-target eradication techniques, which will make rapid and aggressive response a tangible option.

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