**2016 International Student Debates: Solving Problems without Borders**

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Each year, the Entomological Society of America’s (ESA) Student Affairs Committee (SAC) organizes and moderates the student debate competition at the annual ESA meeting; however, 2016 was a special year. ESA hosted the XXV International Congress of Entomology’s (ICE) meeting in Orlando, FL, and thus the ESA SAC worked in tandem with the ICE SAC to organize the International Student Debate Competition. Topics for the debates reflected the ICE 2016 theme of “Entomology without Borders.” Each debate involved teams making a choice regarding policy surrounding international issues. The topics were: (1) What would be the single best policy for improving health of *Apis mellifera* if adopted worldwide? (2) What is the single best strategy for decreasing dengue fever virus (breakbone fever) incidence worldwide? (3) Teams are presenting a grant to a hypothetical international agency to support control measures for an invasive arthropod species. Each team will pick a species and explain to the agency why their species is the most important invasive arthropod in need of management legislation. Below, each topic is presented with an unbiased introduction, followed by the solution-specific stances of each of the debating teams.

**Topic 1: What would be the single best policy for improving health of *Apis mellifera* if adopted worldwide?**

**Unbiased Introduction**

**Rodney Richardson, The Ohio State University, Columbus, OH**

 While numerous large honey bee colony losses have occurred throughout history, none caught the interest of the general public as widely as colony collapse disorder (CCD). Originally recorded in late 2006 and affecting thousands of colonies across dozens of U.S. states, CCD quickly garnered worldwide media attention, inspiring a variety of hypotheses about its origin and potential causes. Among these, the scientific consensus centered on a number of the more plausible hypotheses, including parasitism from the ectoparasitic mite *Varroa destructor*, loss of foraging habitat, disease agents, and pesticides (Johnson et al. 2010, Goulson et al. 2015, Vaudo et al. 2015). Beekeepers rarely report CCD today, though colony survival remains poor (Seitz et al. 2015), so while there is still debate about which environmental factors are most negatively affecting bees, there is general agreement that steps should be taken to improve honey bee health.

Over the past decade of honey bee health research, much attention has focused on a particular class of insecticides, the neonicotinoids. While it was well-known that neonicotinoids demonstrated high acute toxicity to honey bees, unexpected sublethal effects on bee physiology, immunity, and behavior have also been documented (Henry et al. 2012, Di Prisco et al. 2013, Williams et al. 2015). Interestingly, similar associations between nutritional status and honey bee physiology, immunity, and behavior have also been documented (Toth et al. 2005, Alaux et al. 2010, Di Pasquale et al. 2013). Researchers and beekeepers agree that reductions in the quantity and quality of foraging resources, driven by landscape modification, has harmed honey production and colony survival (Sponsler and Johnson 2015, Dolezal et al. 2016, Smart et al. 2016). Even so, much of the scientific research supporting different hypotheses have been conducted on small groups of worker bees at the laboratory scale. Thus, the core issue has evolved beyond questions about how some factors affect individual bees to effects on the complex superorganism that is a colony of bees.

As changes in agriculture and growing urban areas continue to alter the structure of landscapes and the chemical inputs they receive, understanding how different factors influence honey bee populations, both individually and in combination, is an important goal. However, debates about the effects of pesticides on honey bees are nothing new. Indeed, the first formal attempt to determine the consequences of arsenical insecticides on honey bees occurred in the early 1890s when the Association of Economic Entomologists appointed a committee, headed by J. A. Lintner, to the task. While reviewing evidence from F. M. Webster of the Agricultural Experiment Station of Ohio and A. J. Cook of the Michigan State Agricultural College in 1894, the results were “not deemed conclusive” (Lintner 1894). These non-findings were deemed the result of comical blunders in honey bee husbandry and a lack of important toxicological and scientific innovations which included the concept of the median lethal dose (LD50) and the use of experimental controls (Berenbaum 2015).

 While much has changed since these early disputes among honey bee researchers, one central aspect of the disputes remain in the disparities between laboratory and field-level experimental outcomes (Carreck and Ratnieks 2014). While colony-level studies are most field-relevant, the majority of honey bee research occurs in the laboratory, often in cage trials where bees are exposed to treatments and monitored for altered physiology, behavior or longevity. Though laboratory studies are cost-effective, faster, and more straightforward than field studies, the differences between a colony of honey bees and a dozen honey bees in a cage are quite substantial, and laboratory findings are not easily generalized to the colony level. Ultimately, most of the research concerning the vulnerability of honey bees to environmental insults, including poor nutrition and pesticide exposure, is difficult to extrapolate to the economically and ecologically relevant unit of the honey bee, the colony.

**Topic 1: What would be the single best policy for improving health of *Apis mellifera* if adopted worldwide?**

**Neonicotinoid ban except in foliar applications in greenhouses**

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**Faculty Advisor: Jonathan Lundgren, Ecdysis Foundation, Estelline, SD**

 The effects of neonicotinoid insecticides on honey bees necessitate that use of these products should be restricted. Mounting research is revealing that this class of neurotoxic, acetylcholine-inhibiting insecticides causes a significant number of sublethal effects on honey bee health (Charpentier et al. 2014). These effects include decreased foraging success (Yang et al. 2008), impaired navigation (Fischer et al. 2014), suppressed development of hypopharyngeal glands (Hatjina et al. 2013), inhibition of abdominal ventilation movement (Hatjina et al. 2013), negative impacts on the honey bee immune system (Di Prisco et al. 2013), and hive reproductive capacity (Straub et al 2016). Moreover, effects of neonicotinoid insecticides aggravate other stressors on honey bees. For example, the negative effects of *Varroa* mite (Nazzi et al. 2012) and *Nosema* parasite infestations (Doublet et al. 2015) and infections with deformed wing (Di Prisco et al. 2013) and black queen cell viruses (Doublet et al. 2015) are compounded by interactions with neonicotinoids.

 Pest management decisions must weigh the agronomic value against potential environmental harm; scant evidence supports the agronomic benefit of neonicotinoid seed treatments. Consensus among scientific studies suggests that pests are not reduced and yields are not improved in a number of seed-treated row crops relative to untreated fields or fields treated using IPM action thresholds (Wilde et al. 2004, Royer et al. 2005, Seagraves and Lundgren 2012, Bredeson and Lundgren 2015). However, this phenomenon does not translate to all cropping systems, such as vegetable crops (Fleischer et al. 1998, Koch et al. 2004). Despite the lack of evidence for economic benefit of seed-treated row crops, the use of neonicotinoids in agriculture remains widespread. For example, in the United States, at least 42 million ha of three crops (maize, soybean, and cotton) were planted with neonicotinoid seed treatments (Douglas and Tooker 2015). These neonicotinoids can persist in the environment for multiple years and can move out of cropland into neighboring habitats, where they affect aquatic systems and untreated vegetation that bees need for forage (Main et al. 2014). The main sources of this environmental contamination are leaching (Stoner and Eitzer 2012) and wind dispersal (Krupke et al. 2012).

 Contamination of bee forage by neonicotinoids increases the exposure of bees to these toxins. Honey bees are not repelled by, nor are they able to taste, neonicotinoids and preferred neonicotinoid-laced sucrose solutions over sucrose solution alone (Kessler et al. 2015), meaning honey bees cannot select against neonicotinoid-treated plants in the environment. Field collections of bee bread and nectar are contaminated with biologically meaningful levels of neonicotinoid toxins even in habitats not treated with neonicotinoids (e.g., organic farms) (Mogren and Lundgren 2016). Furthermore, field exposure levels are correlated with reductions in honey bee health (Krupke et al. 2012). Thus, honey bees are unable to avoid consuming hazardous levels of neonicotinoids in agricultural regions of the country where they spend most of their time.

 Therefore, increasing bee forage can only benefit pollinators in the presence of restricted use of pesticides. For this reason, restricting the use of neonicotinoids should be prioritized over increasing bee habitat in the environment.

**Topic 1: What would be the single best policy for improving health of *Apis mellifera* if adopted worldwide?**

**Increasing Honey Bees’ Access to Varied, High-Quality Forage**

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**Faculty Advisor: Deborah Delaney**

 As the human population has doubled over the past half-century, shifts in land-use practices, agricultural techniques, and food production strategies have placed new stresses on domestic honey bees (*Apis mellifera* L.), compromising bee health and causing colony losses. Landscapes around the world have become increasingly marked by human development and intensively managed agricultural monocultures. One of the most critical concerns resulting from these changes in land cover is a decrease in the quantity, quality, and overall diversity of floral resources available to honey bees, which has led to significantly reduced productivity by managed honey bees throughout the U.S. (Brodschneider and Crailsheim 2010), as well as in Europe, Japan, and the Middle East (Neumann and Carreck 2010, Potts et al. 2010). Small farms growing a diversity of crops have given way to expansive crop monocultures, and use of synthetic fertilizers has diminished the practice of crop rotation. These crop monocultures are effectively food deserts for pollinators, providing short, synchronous flowering periods that do not meet honey bees’ nutritional needs over the long foraging season (Naug 2009, Vanbergen 2013). Unavailability of floral resources in agroecosystems has resulted in malnourished and unsustainable managed honey bee colonies, and this is generally considered to be a leading cause for colony losses in the U.S. (Brodschneider and Crailsheim 2010, Di Pasquale et al. 2013) and pollinator declines worldwide (Potts et al. 2010).

 Honey bees are not responding to a single threat, but rather are caught in a vortex of confounding stressors, which together debilitate bee health and resiliency at the individual, colony, and metapopulation levels. In addition to inadequate nutrition, these stressors include parasites such as *Varroa destructor* (Anderson and Trueman) mites and *Nosema ceranae* (Fries) ungus, diseases such as Deformed Wing Virus and Acute Bee Paralysis Virus, and exposure to neonicotinoid pesticides (Neumann and Carreck 2010, vanEngelsdorp and Meixner 2010). Targeting one of these threats may have a small positive effect but will fail to reduce the pressure on *A. mellifera* health from other fronts. Our best strategy for protecting honey bees and their valuable services is to focus efforts on maximizing bees’ ability to simultaneously combat multiple stressors. Improving access to varied, high-quality forage will improve bee nutrition, support immune system function, and strengthen overall health, making honey bees more resilient to sources of stress in their environment.

 A single plant species rarely provides the full suite of nutrients bees require, and therefore a varied diet of nectar and pollen from different flowers is crucial to proper development. Deficiency in one or more of the ten amino acids essential for development can limit honey bees’ ability to rear brood (Roulston and Cane 2000); impair the development of hypopharyngeal glands, ovaries, and flight muscles (Di Pasquale et al. 2013), and shorten overall life span (Brodschneider and Crailsheim 2010). Fighting stressors such as disease or exposure to toxins can increase the energetic demands on a colony, furthering the need for bountiful floral resources; for example, bees infected with *N. ceranae* respond by increasing consumption of carbohydrates (Vanbergen 2013). Furthermore, an adequate and varied pollen diet can improve bees’ resistance to *N. ceranae* infection (Di Pasquale et al. 2013) and may reduce vulnerability to other pathogens by promoting immune function (Vanbergen 2013).

 Increasing available high-quality forage for honey bees not only addresses the aim of improving domesticated bee health but could also provide additional benefits to global food production by supporting populations of natural enemies and native pollinators (Potts et al. 2010, Sidhu and Joshi 2016). While alternative strategies, such as limiting pesticide use, have great potential to improve bee health, their application is complicated by conflicts with other agricultural objectives, including pest control. Although there is no silver-bullet solution to honey bee losses, increasing quality forage globally allows for mitigation of multiple stressors simultaneously with a single policy. Improving honey bees’ access to varied forage improves their ability to withstand the complex, synergistic pressures of their ever-changing environment.

**Topic 2: What is the single best strategy for decreasing dengue fever virus (breakbone fever) incidence worldwide?**

**Unbiased Introduction**

**Ashley Yates, The Ohio State University, Columbus, OH**

 The global range of dengue (breakbone fever) has expanded over the last several decades (Messina et al. 2014), placing more than 3.5 billion people at risk for the disease (Brady et al. 2012). The expansion of dengue is exacerbated by increased urbanization, international travel, and the ability of one of the main vectors, *Aedes aegypti* (L.), to thrive in urban environments without effective control (Morrison et al. 2008, Gubler 2011, Murray et al. 2013). *Aedes aegypti* also transmits several other pathogens, including yellow fever, Chikungunya, and Zika viruses. However, dengue is now among the most prevalent mosquito-borne viral illnesses worldwide (WHO 2012).

 Dengue is caused by one of four single-stranded RNA virus serotypes (i.e., DEN-1 to -4) (WHO 2009). The disease manifests as a flu-like illness characterized by a series of symptoms, including fever, rash, joint pain, and vomiting (WHO 2009). Dengue infects an estimated 390 million people annually, and most patients experience mild symptoms (Bhatt et al. 2013). Some patients with dengue will progress to severe dengue or dengue hemorrhagic fever (DHF) and experience loss of plasma, hemorrhaging, or organ damage (WHO 2009). Severe dengue is fatal in less than 1% of patients that receive rehydration treatment (WHO 2009).

 To limit the spread and incidence of dengue, disease prevention has focused on controlling the insect vector. One method is to empty water from containers near houses, eliminating oviposition sites. However, the limitation of this method is the lack of long-term participation of entire communities (Morrison et al. 2008). Insecticides are another widely used method to reduce *Ae. aegypti* populations, but can cause unintended harm to non-target organisms and become ineffective as resistance develops (Marcombe et al. 2012). Thus, vector control requires novel strategies to suppress *Ae. aegypti* populations and limit the spread of dengue. Ideally, the novel strategies should target the adult stage of the vector (Morrison et al. 2008) and require them to mate to ensure the strategy is species-specific (Alphey 2014). These novel control methods seek to introduce a trait that results in lethality (i.e., population suppression) or disrupts disease transmission (i.e., population replacement) (Alphey 2014).

 Novel *Ae. aegypti* control mechanisms include genetic engineering (GE) and biological control. Genetically engineering *Ae. aegypti* with a lethal gene causes mortality in the progeny that inherits the gene (Alphey 2014). This strategy is conceptually similar to the sterile insect technique (SIT), where insects are exposed to radiation then released to mate; the offspring inherit lethal mutations (Alphey 2007). Some GE strategies specifically cause mortality in females, which potentially decreases dengue transmission (Fu et al. 2010). Several novel GE control mechanisms have been developed for mosquito population suppression or replacement (Alphey 2014).

 Another promising control strategy is the use of *Wolbachia* as a biological control agent (Bian et al. 2010, Hoffmann et al. 2011, Iturbe-Ormaetxe et al. 2011, Alphey 2014). When artificially introduced into *Ae. aegypti*, *Wolbachia* can suppress populations by preventing viable offspring unless both males and females are infected with the same strain of *Wolbachia* (Iturbe-Ormaetxe et al. 2011). In addition, some strains of *Wolbachia* can limit the spread of dengue through population replacement, which renders *Ae. aegypti* less susceptible to dengue viral infection (Bian et al. 2010, Iturbe-Ormaetxe et al. 2011).

 These novel vector control strategies (i.e., genetic engineering and biological control) are expected to be species-specific and have great potential to reduce *Ae. aegypti* populations and dengue transmission worldwide.

**Topic 2: What is the single best strategy for decreasing dengue fever virus (breakbone fever) incidence worldwide?**

**Genetically Engineered Mosquitoes with Lethal Genes**

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**Faculty Advisor: Fred Gould**

Dengue fever virus (DENV), transmitted by *Aedes* mosquitoes, is found in many tropical and subtropical regions of the world (WHO 2012). Dengue causes more human morbidity and mortality than any other arbovirus (Kraemer et al. 2015). The global burden of dengue is estimated at 390 million people infected (Achee et al. 2015). It is endemic in more than 100 countries and spreading, highlighting the need for more effective control methodologies (Achee et al. 2015). Genetically modifying (GM) the primary dengue vector *Aedes aegypti* to contain and spread lethal genes will suppress *Ae. aegypti* population size and/or suppress disease transmission, resulting in a reduction of dengue fever incidence while also decreasing other diseases *Ae. aegypti* transmits, primarily Zika, Chikungunya, and yellow fever viruses (Olson and Franz 2015). Vector control through the use of lethal genes is the most promising strategy for dengue control because lethal genes can be used in versatile, targeted, reversible, and responsible approaches.

Dengue vaccine development is difficult because there are four confirmed serotypes, with a fifth putatively identified (Normile 2013). The large number of serotypes impedes progress because control strategies that target dengue virus should be effective against all serotypes (Sim and Hibberd 2016). *Wolbachia*-based strategies that decrease dengue transmission have this same requirement but have shown variable success among serotypes. Furthermore, serotypes share only 65–70% amino acid similarity (Sim and Hibberd 2016), but studies that show the effectiveness of *Wolbachia* against dengue rarely test all four serotypes (Ye et al. 2015, Mousson et al. 2012). Alternatively, strategies that target vector population size do not need to be tested against individual serotypes; a dead mosquito will not transmit any pathogen. The probability of the virus developing resistance to the lethal gene strategy is reduced compared to strategies that put direct selective pressure on the virus, such as the *Wolbachia* strategy (Bull 2015). Population suppression using lethal genes has already reduced wild *Ae. aegypti* populations in Brazil, Panama, Malaysia, and the Grand Caymans (Harris et al. 2012, Lacroix et al. 2012, Carvalho et al. 2015). Further, the geographically diverse success of these field trials indicates this strategy is less sensitive to environmental factors than *Wolbachia*, which has been shown to have temperature dependencies (Ulrich et al. 2016).

Genetically modified mosquitoes used for population suppression have been extensively tested in laboratories and small-scale field-cage trials (Alphey et al. 2013, Bourtzis et al. 2016). Understanding molecular mechanisms, such as RNAi, and biochemical and genetic mechanisms, maximizes benefits while mitigating the risk of unpredictable outcomes. Additionally, horizontal gene transfer of lethal genes has never been observed, and studies have shown no non-target effects on predators (Nordin et al. 2013). Unlike self-perpetuating strategies, like inoculating male mosquitoes with *Wolbachia* bacteria*,* lethal genes are self-limiting, which reduces unexpected or long-term risks compared to population replacement strategies (Alphey et al. 2013). Releases can be terminated if needed, limiting negative consequences to a small time period (Gorman et al. 2015, Bourtzis et al. 2016).

Lethal gene technology is the most responsible choice for near-term dengue control. The potential ecological impacts are lower than current insecticide-based strategies, and the biochemical and genetic mechanisms are well characterized. Public engagement has been a cornerstone of GM mosquito releases (Carvalho et al. 2015). While decreasing global dengue incidence likely will require a suite of effective methods for lasting control, we consider GM *Ae. aegypti* expressing lethal genes to be the most promising technology to decrease dengue fever worldwide.

**Topic 2: What is the single best strategy for decreasing dengue fever virus (breakbone fever) incidence worldwide?**

**Biological Control Using *Wolbachia***

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**Faculty Advisor: Peter Dunn**

Dengue fever is among the most widespread arthropod-borne diseases in the world, infecting approximately 390 million people each year (Bhatt et al. 2013). The yellow fever mosquito, *Aedes aegypti,* is the primary vector of dengue and is found throughout subtropical and tropical regions. Current research in biological control has revealed that a bacterium, *Wolbachia* *pipientis* (*Wolbachia*), has several advantages over the use of genetically engineered (GE) mosquitoes with lethal genes for decreasing dengue fever incidence worldwide. Most notably, *Wolbachia* interferes with the mosquito’s ability to transmit dengue virus by limiting viral replication of all serotypes and reducing the number of viral particles transmitted by up to 90% (Ferguson et al. 2015).

*Wolbachia* is vertically transmitted by the female mosquito to all progeny and exhibits a feature known as cytoplasmic incompatibility, which prevents uninfected females from producing viable offspring after mating with *Wolbachia*-infected males (Xi et al. 2006). Therefore, only matings between uninfected mosquitoes result in uninfected progeny. All other pairings result in either nonviable embryos or *Wolbachia*-infected progeny. After only a few releases of transinfected mosquitoes, the biological control agent proliferates naturally throughout the population, requiring no further supplementation (Hoffmann et al. 2014).

The introduction of *Wolbachia* is a cost-effective and self-sustaining control technique. An average of 14 transinfected *Ae. aegypti* mosquitoes released per hectare per week in Cairns, Australia, was enough to drive *Wolbachia* infection to near total fixation through a population spanning ~2,000 ha within a few months following releases (Hoffmann et al. 2011). *Wolbachia* remained at near-fixation levels in the population and maintained viral blocking two years after releases of *Wolbachia*-infected mosquitoes had ceased (Hoffmann et al. 2014). Models suggest that *Wolbachia* can reduce dengue virus transmission by more than 80% (Ndii et al. 2016). In contrast, the release of up to 14,000 GE mosquitoes with lethal genes per week was required to suppress populations in the Grand Cayman Islands (Harris et al. 2012). Moreover, difficulties in mass-production of GE mosquitoes resulted in a reduced study area from 55 ha to 16 ha plots—less than 2% of the study areas in Cairns (Harris et al. 2012).

*Wolbachia* satisfies current regulatory standards for release in seven countries, while more research is needed before large-scale releases of GE mosquitoes are approved (NASEM 2016, Xi and Joshi 2016). Transinfected *Ae. aegypti* are unlikely to cause environmental harm because *Wolbachia* is incapable of horizontal transmission to humans and other animals (Popovici et al. 2010, Murray et al. 2016). Therefore, using *Wolbachia*-infected *Ae. aegypti* to control dengue transmission will not negatively impact other organisms in the environment. Additionally, *Wolbachia* does not eliminate or eradicate a species, whereas GE mosquitoes with lethal genes eliminate the primary vector, potentially allowing an alternative vector to exploit the open niche (NASEM 2016). If this were to occur, elimination of the new species would be required, including investment in developing new lines of GE mosquitoes. Thus, using *Wolbachia* infected *Ae. aegypti* to reduce dengue transmission is superior to strategies that focus on eradicating mosquito species to control arboviruses.

 Arthropod vectored diseases are on the rise across an increasingly connected global community. As a result, we must use the best possible tools currently available to protect human health worldwide. Biological control using *Wolbachia* is the most effective, safe, and sustainable way for decreasing the global spread of dengue fever incidence while keeping mosquitoes in the ecosystem with a reduced capacity to transmit the pathogen and is available for deployment today.

**Topic 3: Choose the most important invasive arthropod internationally to focus control efforts on.**

**Unbiased Introduction**

 **Edmund J. Norris, Iowa State University, Ames, IA**

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Invasive species can have enormous impacts on the ecosystems to which they are introduced. The biological diversity in many stable ecosystems evolved slowly, producing a complex system of species interdependence and interrelationship. Because of the presence of numerous predator and autotroph species, natural systems are capable of maintaining homeostasis and recovery if a minor disturbance should occur (Drake 2005). These ecological buffers are an important part of stable ecosystems that prevent immediate and drastic change from occurring. Because invasive species evolve in different environments with different ecological stressors, their newly invaded ecosystems may not be capable of tolerating their insult, and in turn, experience rapid alteration (Mack et al. 2000).

The introduction of invasive species occurs through a variety of intentional and accidental means. Motives for intentional releases have ranged from highly romantic, as in the introduction of starlings in 1890 simply due to their mention in a variety of Shakespeare plays (Long 1981), to practical, such as the release of the cane toad (*Rhinella marina*) to control cane beetle (*Dermolepida albohirtusm*) populations in Australia (Price 1996). Of course, accidental releases are the most common and are particularly important in our modern world. Our global economy has afforded us easy transit and an abundance of commodities, but not without consequence. The spread of the Asian tiger mosquito is a perfect example of a pest carried to new environments by global trade routes. By hiding in small containers and tires, this pest is easily trafficked to new environments, often spreading various arboviruses to vertebrate hosts in its newly acquired, non-autochthonous environment (Juliano and Lounibos 2005).

Indeed, the impact of invasive pests can be quite severe and lead to significant economic losses. The brown planthopper (*Nilaparvata lugens*) has been implicated in the destruction of lowland rice that accounts for 75% of global food supply (Brar and Khush 2009, Lou and Cheng 2011, Savary et al. 2012). In 2006, the destruction of approximately 9.4 million hectares of rice was reported in China alone (Catindig et al. 2009). Infestations of *Varroa destructor* can destroy honey bee colonies, which in turn are responsible for pollinating various crops. It has been estimated that insect pollination is responsible for approximately 9.5% of the world’s food supply(Grunewald 2010), making its potential impact on global food supply significant. The damages associated with invasive pests can also present themselves quite differently. They may include matters of public health, agriculture, forestry, aesthetic depreciation of commodities and property, and the destruction of natural ecosystems (Huber et al. 2002). The variety of damages associated with invasive pest species makes their control paramount but can also cause the implementation of control strategies to be quite difficult. Because there is no single method that can curb invasive pest populations, control strategies relying upon advanced knowledge of pest biology, abundance, and the scope of impact on natural ecosystems and/or the economy must be employed(Eden et al. 1985).

As such, it is imperative that we prepare to combat invasive threats in order to quickly mitigate their effects on the economy and natural ecosystems whenever possible. We can limit the long-lasting effects of invasive pests on our economy and ecosystems by identifying their presence in various natural or agricultural environments, characterizing their biology, and implementing targeted, integrated pest management strategies. For this debate, each team has been tasked with describing the economic and ecological impacts of a chosen invasive pest. The debating teams will then demonstrate the need for immediate appropriations from a hypothetical international funding agency to combat the pest. May the most pestilent pest win!

**Topic 3: Choose the most important invasive arthropod internationally to focus control efforts on.**

***Varroa destructor***

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**Faculty Advisor: Baldwyn Torto**

 Insect pollination contributed to 9.5% of world agricultural output in 2005, worth ~153 USD billion (with ~25% attributed to honey bees worth ~38 USD billion) (Gallai et al. 2009). This excludes similar services to more than 80% of wild plants, some of which directly benefit livestock, hence grossly undervaluing their true worth (Potts et al. 2010). Honey bees increase yield in 96% of insect-pollinated crops worldwide (Potts et al. 2010). Additionally, sales of honey, wax, propolis, royal jelly, and venom fetch extra income for farmers, hence diversifying their livelihoods.

 The reality of honey bee colony declines around the world poses a substantial threat to global food and nutritional security, livelihoods, and biodiversity conservation. This scenario is likely to affect the attainment of the sustainable development goal (SDG) 2, which includes ending hunger, achieving food security, improving nutrition, and promoting sustainable agriculture (UN News Center 2016). In regions such as North America and Europe, where some crops depend on migratory pollination services, increases in winter colony losses from ~10% to more than 30% within the last decade have constrained efforts to increase the colony numbers to meet rapidly growing service demands (Potts et al. 2010). Furthermore, with the world’s population expected to approach nine billion by 2050 (Keesstra et al. 2016), this situation is likely to deteriorate without affordable, sustainable, and environmentally benign interventions implemented in an appropriate and timely manner.

 Among the drivers of colony losses, pests, pathogens, and diseases are considered the most important. Most notably from this group, the mite *Varroa destructor* Anderson and Trueman*,* a native ectoparasite of the Asian honey bee, *Apis cerana* Fabricius, accidentally introduced in honey bee (*Apis mellifera* L.) colonies in Europe and North America, from where it has expanded its host range globally (Rosenkranz et al. 2010). This hemolymph-feeder parasitizes adults, last instars, and pupae (Dietemann et al. 2013). The effects of hematophagy include physical deformities (stunted abdomen, deformed wings) and reduced vitality and longevity (Genersch 2010). However, more severe effects from this parasite stem from the viruses it vectors, which have been implicated in large-scale colony collapses. Some examples of these viruses include Deformed Wing Virus, Chronic Bee Paralysis Virus, Acute Bee Paralysis Virus, Israeli Acute Paralysis Virus, and Kashmir Bee Virus (Le Conte et al. 2010). Characteristic symptoms of these infections include wing deformities, abnormal trembling motion of the wings, loss of hair from the thorax and abdomen resulting in hairless black bodies, and the inability to fly, ultimately leading to death (Genersch 2010).

 Research activities in the last two decades have led to the development of an array of mite control arsenals. These diverse management tools are broadly categorized into three areas: (1) chemical treatment; (2) biotechnical intervention (e.g. drone brood removal); and (3) bee breeding (primarily for Varroa-sensitive hygienic behaviors) (Plettner et al. 2016). Synthetic acaricides taint hive products, select for pesticide resistance in the mite, and may harm bees (Rosenkranz et al. 2010).

 Biotechnological manipulation is too labor-intensive and unsuitable for large-scale operations, whereas breeding stock maintenance is capital-intensive (Plettner et al. 2016). However, Africanized bees and other small bee populations around the world seem to survive mite infestation without any treatment (Muli et al. 2014). Understanding the bee coping mechanisms will likely reveal new insights and avenues for new tools. This is part of ongoing interdisciplinary research at the African Bee Reference Laboratory at the International Centre of Insect Physiology and Ecology (*icipe*), Nairobi, Kenya. The take-home message; an investment in *V. destructor* management will definitely contribute to a safer future through sustainable pollination services.

**Topic 3: Choose the most important invasive arthropod internationally to focus control efforts on.**

**Brown planthopper**

**R. Murphy Coy, Blessing Ademokoya, Olufemi Ajayi, Adrian Pekarkic**

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Current population, climate, and food security (availability, stability, access, and utilization) models predict an ever-increasing population, a varied climate, and declining land and water resources threatening rice production (Schmidhuber and Tubiello 2007, Nguyen 2002). Southern and southeastern Asia houses >30% of the world’s population, and the economies and cultures are heavily influenced by rice (*Oryza sativa* L.). Asia produces and consumes 90% of the world’s rice, accounting for 50–70% of the population’s caloric intake and nearly half of the world’s population (Bishwajit et al. 2013, Jena and Kim 2010). While these economies have grown at unprecedented rates, it remains the second poorest region globally and largely food insecure with 20% of the population undernourished and >500 million people living in poverty (Bishwajit et al. 2013). Poverty and food insecurity, specifically rice insecurity, must be addressed with coordinated international efforts to bring food and economic stability to this region.

Increases in rice yields could result in higher incomes for subsistence farmers and developing economies while reducing undernourishment and poverty (Nguyen 2002). While the green revolution introduced improved rice varieties and increased yields, recent decreases in yields have become more common as rice demand has outpaced supply since 2000 (IGC 2014, Nguyen 2002). Overreliance on chemical fertilizers, pesticides, large migrating pest populations, and the adoption of continuous rice cultivation have had negative consequences, most notably the shift in the pest status of the brown planthopper, *Nilaparvata lugens*.

Planthoppers are herbivorous, sap-feeding hemipterans that include numerous agricultural pests. Brown planthopper is monophagous on *Oryza* and *Leersia* (cut rice) where damage is a direct result of feeding; these insects also indirectly damage rice by vectoring rice grassy stunt and rice ragged stunt viruses (Jena and Kim 2010, Renganayaki et al. 2002). Losses from brown planthopper are often catastrophic, reducing yields by 40%, damaging 20 million hectares in 2005 and 2008 (Xue et al. 2014, Jena and Kim et al. 2010).

The brown planthopper overwinters in southeastern and southern Asia. It is a dimorphic species, whose macropterous form is capable of long-distance migrations throughout the region. Brown planthopper outbreaks were infrequent before the green revolution, but since then has been a devastating and persistent threat to rice production (Hu et al. 2015, Xue et al. 2014, Jena and Kim 2010, Cohen et al. 1997). With a changing climate, brown planthopper will be a greater threat with additional generations per year and a 206% increase in overwintering range by 2050 (Hu et al. 2015, Schmidhuber and Tubiello 2007). Increasing the overwintering range provides larger reserve and migrating populations to invade uninfested areas earlier in season.

Annually, 37% of rice is lost, with significant losses from brown planthopper feeding and disease transmission (Sparks et al. 2012). Reduction in losses through best management practices, increasing farmer education and support, and incorporating genetic resistance into rice cultivars is key to feeding the world’s growing population and eradicating poverty. Previously, the selection of winged morphs with growth regulators (Bertuso et al. 2002, Ayoade et al. 1999, Iwanga et al. 1985) was met with limited success; however, all wing development genes are now identified (Xue et al. 2014), and studies with RNA interference (RNAi) and two brown planthopper insulin receptors resulted in binary control of wing outcome. Cultivars incorporating RNAi to select for brachypterous forms in overwintering areas could reduce losses and migratory populations until cultivars for field level control are developed. With coordinated international efforts, future losses from brown planthopper can be mitigated, resulting in economic and food security.

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