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Student Debates

Entomology in the 21st Century: Tackling Insect Invasions, Promoting Advancements in Technology, and Using Effective Science Communication—2018 Student Debates

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Abstract

The 2018 student debates of the Entomological Society of America were held at the Joint Annual Meeting for the Entomological Societies of America, Canada, and British Columbia in Vancouver, BC. Three unbiased introductory speakers and six debate teams discussed and debated topics under the theme ‘Entomology in the 21st Century: Tackling Insect Invasions, Promoting Advancements in Technology, and Using Effective Science Communication’. This year’s debate topics included: 1) What is the most harmful invasive insect species in the world? 2) How can scientists diffuse the stigma or scare factor surrounding issues that become controversial such as genetically modified organisms, agricultural biotechnological developments, or pesticide chemicals? 3) What new/emerging technologies have the potential to revolutionize entomology (other than Clustered Regularly Interspaced Short Palindromic Repeats)? Introductory speakers and debate teams spent approximately 9 mo preparing their statements and arguments and had the opportunity to share this at the Joint Annual Meeting with an engaged audience.

Key words: student debates, invasive species, science communication, emerging technologies

The student debates are held every year at the annual meeting of the Entomological Society of America (ESA). The student debates are a lively, cross-examination style event that give participating students the opportunity to enhance their public speaking skills, engage in an in-depth critical thinking exercise, and showcase this to an engaged audience. Student members of ESA have the opportunity to participate either as introductory speakers or as a member of a debate team. The theme of the student debates as well as the debate topics are determined by a subcommittee of the Student Affairs Committee (SAC) of ESA and this subcommittee also organizes and hosts the student debates. Each topic within the student debates is introduced by an unbiased introductory speaker. Following this, two teams with different stances have the opportunity to defend their position on the topic as well as cross-examine the opposing team.

The SAC subcommittee recruits ESA members as judges and debate teams are scored on the quality of their introduction, cross-examination, rebuttals, and response to questions as well as their use of time, strength of the supporting literature, abstract, and ability to meet deadlines leading up to the debates. While the student debates may take place at the ESA annual meeting, teams and introductory speakers are preparing for this event well in advance. Debate teams spend close to 9 mo preparing their references, statements, and working out their arguments to defend their stance.

The theme and topics selected every year are meant to address present-day topics and issues relevant to the ESA membership and conference attendees. For the 2018 student debates held in Vancouver, BC, all debate topics were 'issue' topics and teams chose a position to defend. The theme for the 2018 student debates was 'Entomology in the 21st Century: Tackling Insect Invasions, Promoting Advancements in Technology, and Using Effective Science Communication' and the debate topics were as follows:

1) What is the most harmful invasive insect species in the world?
2) How can scientists diffuse the stigma or scare factor surrounding issues that become controversial such as genetically modified organisms, agricultural biotechnological developments, or pesticide chemicals?
3) What new/emerging technologies have the potential to revolutionize entomology (other than Clustered Regularly Interspaced Short Palindromic Repeats [CRISPR])?

The 2018 student debates are summarized below and include the unbiased introduction and the response from the opposing teams on the topics.

The student debates are an excellent opportunity for students to work collaboratively and engage in an exciting, fast-paced debate on topics relevant to entomology. The SAC would like to encourage students to establish teams (including multi-university teams) or sign up to be an unbiased introductory speaker. The SAC also encourages the ESA membership to attend the student debates, challenge the participants with questions, and consider volunteering as a judge.

What Is the Most Harmful Invasive Insect Species in the World?

Unbiased Introduction by Lina Bernaola

Invasive species is a broad term that is simply defined as any plant or animal that is not native to an ecosystem and causes damage to the environment, economy, or health of other organisms (National Wildlife Federation 2018). Typically, the most successful invasive species are capable of rapidly spreading to new areas and thriving in different environments. Pimentel et al. (2005) estimated over $120 billion of damage in the form of lost crops, contamination of grain, competition with native plants, as well as several other factors that could be attributed to invasive species (both plants and animals). In this debate, we will focus on two invasive insects by comparing the European honey bee, *Apis mellifera* (Linnaeus) (Hymenoptera: Apidae), and the Asian tiger mosquito, *Aedes albopictus* (Skuse) (Diptera: Culicidae). The threat of spreading disease-causing pathogens when the Asian tiger mosquito takes a blood meal provides more visibility to the harm of this invasive species. However, European honey bees have contributed to the reduction of native species of both animals and plants. When they crowd out competition and selectively pollinate certain flowers instead of others, *A. mellifera* can cause shifts in the ecosystem. Regarding human interaction, a bite from the Asian tiger mosquito is mild and sometimes unnoticed; however, the pain of honey bee stings is relatively stronger. However, the pain of the bee's sting is temporary and does not carry the same risk of spreading pathogens.

Honey bees are often seen as a critical pollinator and less often as an invasive species. Honey production is a massive industry, but the job of pollinating several other major crops far exceeds that value. A study conducted by the United States Department of Agriculture estimated the pollination service of bees to be close to 10 billion dollars per year (Buchmann and Nabhan 1997). Losing these European honey bees—to disease, mites, colony collapse, and other threats—would cause disruptions in commercial agriculture, because approximately three quarters of staple crops raised globally rely on pollination (Klein et al. 2007) by indigenous and non-native species. On the other hand, the introduction of *A. mellifera* to various parts of the world has affected native pollinators by depriving other insect species some opportunities for gathering pollen and nectar (Apis Information Resource Center 2018). Furthermore, plants preferred by *A. mellifera* sometimes differ from plants favored by native pollinating species, thereby molding the landscape even beyond the farmlands and orchards where commercial hives are used. Finally, there is a risk to human health in the form of anaphylactic reactions due to a bee sting, which sometimes leads to death. Flabbee et al. (2008) reported mortality rates of approximately 1% in his study of patients admitted to hospitals in France, from 2003 to 2005, on such acute allergic reactions.

The Asian tiger mosquito more immediately affects quality of life, because the species is known to transmit the causative agents of chikungunya and dengue in some areas. Globalization and other factors have facilitated the spread of *Ae. albopictus*, thus providing more prominence in media outlets. International shipping of tires (Cornel and Hunt 1991) and other means have allowed the species to reach most continents. The species has also been successful due to its ability to adapt to new environments, bolstered by their eggs being able to resist cool temperatures and long periods of desiccation (Hawley 1988, Benedict et al. 2007). Several authors have reported and made efforts to model the spread of *Ae. albopictus* using current trends of the mosquito's occurrences as well as algorithms specifically aimed at understanding ecological footholds of a given species (Stockwell 1999, Benedict et al. 2007, Bonizzoni et al. 2013). Most occurrences are still in Asia, but a quarter of those surveyed were in the Americas, and an even smaller portion in Europe (Kraemer et al. 2015). Controlling Asian tiger mosquito populations can be accomplished in part through the use of insecticides, whether by spraying or using treated netting; however, this carries negative consequences for human and environmental health (Benelli 2015).

Each non-native insect brings its own challenge, ranging from ecological to economic, to the environments they have invaded. Society has enabled both *A. mellifera* and *Ae. albopictus* at times but has also grappled with how to best manage these invasive insects to reduce their impact.

Team 1 Stance: Apis mellifera represents an unaddressed threat to global agricultural stability
Team Members: Benjamin Lee, Dane Elmquist, Abigail Cohen, Adrian Marshall, and James Hepler
Faculty Advisor: Dr. Jeb Owen, Washington State University

The definition of an 'invasive species' is controversial, with most debate focusing on the role of human activity in facilitating an introduced organism's success and on the consequences of that success (Valéry et al. 2008). Here we argue that the European honey bee, *A. mellifera*, not only meets all criteria of invasiveness, but that it is the most harmful invasive arthropod in the modern world. Following its deliberate introduction into North America in the 17th century, *A. mellifera* escaped captivity and rapidly invaded North America (Moritz et al. 2005). Despite *A. mellifera*'s charisma and economic prominence, this biological coup has profoundly damaged indigenous pollinator communities (Goulson 2003). More alarming, however, is that the utility of the honey bee has lured the global agricultural community into an overreliance that is increasingly difficult to escape.

When a habitat is invaded by honey bees, native pollinators experience niche competition for local floral resources. Numerical superiority, social behavior, and generalist feeding habits give *A. mellifera* a decisive advantage over their mostly solitary and specialized competitors, which can result in dramatic declines in native pollinator communities (Potts et al. 2016). Another destructive consequence of honey bee invasion is the shifting of local plant communities toward species favored by honey bee visitation. As these newly dominant plants are themselves usually introduced, indigenous communities of plants and the fauna that rely upon them are destroyed in a cycle of ecological reengineering initiated by *A. mellifera* (Goulson 2003). Furthermore, the introduction and management of *A. mellifera* has damaged native pollinator communities through the spread of exotic parasites. In Britain, *A. mellifera* is found to share deformed wing virus strains with native bumble bees, indicating *Apis* as a source of emerging infectious diseases (EIDs) in native pollinators (Fürst et al. 2014). Host shifts of introduced hive pests, such as *Aethinatumida* (Murray) (Coleoptera: Nitidulidae), also threaten native pollinators (Potts et al. 2016).

The negative environmental impacts of *A. mellifera* are mostly dismissed simply because honey bees are considered necessary for a third of the world's crop production. Indeed, movable hives of *A. mellifera* are well-suited to pollinating vast monocultures of crops, and this superficially perfect matching has resulted in incredibly productive intensive agricultural operations (Klein et al. 2007). Unfortunately, this system is both unstable and unsustainable. Global honey bee population declines have already cost $5.7 billion per year in lost agricultural production, with losses disproportionately impacting nutritionally vulnerable regions in Southeast Asia, Africa, and Central America (Allen-Wardell et al. 1998, Chaplin-Kramer et al. 2014). Additionally, the global emergence of pests and pathogens of honey bees has begun a textbook cycle of heavy agrochemical use and pest resistance. These developments have increased the rental price of hives even as massive increases in pollinator-dependent crop plantings outstrip the global supply of managed honey bees (Holden 2006, Aizen and Harder 2009).

The complications perpetuated by the global 'success' of *A. mellifera* highlight the need for native pollinators currently threatened by land-use practices. Native pollination services are equally vital as *A. mellifera*'s in several cropping systems, and in some cases yield superior results (Garibaldi et al. 2013). However, the cycle of agricultural intensification induced by the monopoly of honey bees on pollination services reduces biodiversity in native pollinator communities, negating this 'free' service (Kremen et al. 2002).

The stakes are increasing even as the line we walk grows thinner. Our shortsighted struggle to maintain adequate supplies of *A. mellifera* has constrained our ability to identify and cultivate replacement species. The global community must recognize the threat that our overreliance on *A. mellifera* poses to the ecological and economic stability of the world and put forth solutions to preserve native biodiversity and ecosystem services.

Team 2 Stance: The Asian tiger mosquito, *Aedes albopictus*, represents an immediate threat to human health

Team Members: Adrian Pekarcik, Emily Justus, Kendall King, Tae-Young Lee, Carlos Esquivel

Faculty Advisor: Dr. Joe Raczkowski, the Ohio State University

The Asian tiger mosquito, *Ae. albopictus*, is the most harmful invasive insect species in the world due to its rapid geographic expansion and its potential threat to human health (Global Invasive Species Database 2015). *Aedes albopictus* is endemic to East Asia and islands in the western Pacific and Indian Oceans but has been unintentionally introduced and subsequently established in every continent, except for Antarctica, in the past four decades due to globalization and international travel (Bonizzoni et al. 2013). *Aedes albopictus* develops in small, shaded habitats that collect water and are typically associated with human habitation. In urban areas mated females lay eggs singly on the stagnant water in human-made objects including tires, gutters, bird baths, pools, and water-collecting trash (Pichler et al. 2018). Furthermore, *Ae. albopictus* populations in urban areas are generally found at higher densities with faster larval developmental rates and greater adult longevity (Li et al. 2014). These characteristics allow *Ae. albopictus* to outcompete other invasive mosquito species like *Aedes aegypti* Linnaeus (Diptera: Culicidae) in urban environments (Juliano et al. 2004). Climate change is predicted to favor additional geographic expansion of *Ae. albopictus*; diapausing eggs will be better able to survive in more northerly habitats (Diniz et al. 2017).

Unlike other mosquito vector species *Ae. albopictus* has diurnal activity and aggressive biting preference toward humans which increases the chances of blood feeding and disease transmission in human-occupied environments (Li et al. 2014). One study reported the *Ae. albopictus* biting rate as 30–48 bites per hour (Global Invasive Species Database 2015). Nearly half of the world's population is at risk of contracting one of several vector-borne diseases *Ae. albopictus* vectors including chikungunya, dengue, eastern equine encephalitis, and Zika (Gratz 2004). *Aedes albopictus* could also act as a vector bridge between humans and other animals for diseases such as West Nile or La Crosse (Gratz 2004). There are currently no successful vaccines available for these diseases (Benelli and Mehlhorn 2016). Medical costs from the diseases transmitted by *Ae. albopictus* were estimated at $2.1 billion (Shepard et al. 2011). Productivity losses and income losses are more notable during epidemics and ultimately impact both workers and their employers (Gopalan and Das 2009). Despite extensive global control efforts, *Ae. albopictus* management is difficult and costs upward of tens of millions of dollars annually (Gubler 2002).

Management of *Ae. albopictus* primarily relies on chemical control, although cultural control plays an important role (Pichler et al. 2018). Cultural control focuses on the elimination of water-holding containers around urban areas to prevent egg laying by females. Although local efforts have been successful, it is nearly impossible to eliminate established *Ae. albopictus* populations as continuous scouting and appropriate control tactics are necessary (Bonizzoni et al. 2013). Globally, mosquito chemical control utilizes broad-spectrum insecticides including organochlorines, carbamates, organophosphates, and pyrethroids which have known off-target effects on honey bees, native pollinators, and other beneficial insects (Ginsberg et al. 2017). Management for adults often requires multiple fogging applications which often fail to contact resting individuals (Pichler et al. 2018). In 2016 in South Carolina a single aerial application of naled, an organophosphate used for mosquito management, killed about 2.5 million bees (Guarino 2016). Due to the widespread and continuous use of insecticides, *Ae. albopictus* has developed resistance to pyrethroids in

Africa, southeast Asia, India, the Mediterranean, and United States (Marcombe et al. 2014, Pichler et al. 2018). Newer technologies including sterile insect technique and *Wolbachia* endosymbionts are promising tools for mosquito control; however, they are still under investigation and far from use in a large-scale and public areas (Benelli 2015).

How Can Scientists Diffuse the Stigma or Scare Factor Surrounding Issues That Become Controversial Such as Genetically Modified Organisms, Agricultural Biotechnological Developments, or Pesticide Chemicals?

Unbiased Introduction by Kayleigh Hauri

The intersection of science and policy has been highlighted in recent years by the rising importance of topics such as climate change and the increased use of biotechnologies. A significant divide in the opinion of scientists and the general public often marks these controversial topics, and misinformation about the science can shape public opinion and political policy. The effect of misinformation can be clearly seen, for example, in the controversy surrounding childhood vaccination. Because of a single study incorrectly linking vaccines to autism, the rates of vaccinations in the developed world have decreased to the point that diseases such as mumps, which had not been seen in decades, have made a resurgence (Doja and Roberts 2006, Chang 2018). This is true even though the study has been debunked numerous times, illustrating how insidious the spread of misinformation can be when it comes to the lay population's understanding of science. Therefore, it is critical that we investigate the question: How can scientists diffuse the stigma or scare factor surrounding issues that become controversial such as genetically modified organisms, agricultural biotechnological developments, or pesticide chemicals?

There are several interesting global patterns that should be considered while discussing this topic. In general, public perception of science is high. Seventy-two percent of Americans believe that government investment in engineering and technology pays off in the long run, and 71% said the same of basic research (Funk and Rainie 2015). This attitude is not unique to the United States: a study from this year, which polled over 14,000 people from 14 developed and developing countries, reports that 63% of respondents said that science is 'very important' to society in general (3M 2018). But this optimistic attitude begins to break down when it comes to controversial issues such as genetically modified organisms, agricultural biotechnological developments, and pesticide chemicals. Again, the pattern is global. Fifty-seven percent of the general public in the United States believes that genetically modified (GM) foods are unsafe to eat (Funk and Rainie 2015); a study in the United Kingdom and Poland found that 27.7% of respondents showed negative attitudes toward GM foods (Popek and Halagarda 2017), and over two-thirds supported mandatory labeling. In Korea, a study found that 58.8% of those surveyed believed that GM foods were risky to human health (Kim et al. 2018). This is all in the face of large amounts of scientific evidence that genetically modified organisms (GMOs) are not only safe to eat (Nicolia et al. 2014), but often benefit the environment as well (Mannion and Morse 2012).

Perhaps unsurprisingly, policy decisions often stem from public perception rather than scientific recommendation. Recently, the European Court of Justice ruled that crops created with gene-editing techniques such as CRISPR must go through the same approval process as traditional GMOs, which is lengthy and difficult to pass (Purnhagen et al. 2018). The authors credit a rising mistrust of science as a contributing factor to a decision that was surprising to many scientists working on the gene-editing technology. With the slightly more complex issue of pesticides, continuing public concern over government-approved pesticides suggests public mistrust of regulatory institutions. For climate change, public perception of any scientific dissent—even extremely low levels—undermines support for environmental policy (Aklin and Urpelainen 2014).

Many controversial scientific topics continue to play out in our political and social spheres. Two possible avenues to address stigma and scare factor of scientific issues are 1) trust building through community outreach and 2) increasing science literacy through primary and secondary education. There is immense potential to improve quality of life with scientific advancement, but implementation of these advancements will require public buy-in.

Team 1 Stance: Changing minds with education reform
Team Members: Christopher McCullough, Whitney Hadden, Max Ragozzino, Morgan Roth
Faculty Advisor: Dr. Douglas Pfeiffer, Virginia Tech

The modern world is inundated with an unprecedented amount of information, leaving us to decipher fact from fiction. Biased presentation and poor evaluation of these sources has led to widespread misinformation regarding controversial scientific topics. This is exacerbated by those who, in good faith but poor understanding, further disseminate deliberate misinformation to others. There are many career scientists that want to engage with the public and earn their trust; however, they are limited in their ability to reach the public. Alternatively, there is an established group of dedicated people who engage with the public and use the scientific method on a near daily basis: K-12 teachers. As fellow scientists, we need to help educators reform education by moving away from fact memorization and standardized tests, and toward the implementation of critical thinking pedagogies. We believe that the most effective way to diffuse the stigma surrounding controversial scientific topics is to reform primary and secondary education through the teaching of critical thinking skills, creating a populace that is better able to discern the arguments relating to controversial topics.

By focusing on primary and secondary education, we can utilize a system that has 3.7 million instructors ready to teach 56.6 million students in over 125,000 schools (National Center for Education Statistics 2018). Students in primary and secondary school are more open-minded learners compared to adults. Children already learn about the world in a scientific manner, in that they analyze patterns, draw conclusions from data, and learn from others (Gopnik 2012). Children and adolescents are more flexible than adults when creating new hypothesis and evaluating new information (Gopnik et al. 2017). As we age, experience shapes our beliefs more than new information, especially if that information contradicts previously held ideas (Gopnik et al. 2015). Educators are perfectly positioned to develop the natural curiosity that children possess (Florea and Hurjui 2015). Moving through the K-12 systems also allows for constant and repeated opportunities to enhance critical thinking skills.

What is critical thinking? It is a reflective process that focuses on what to believe or do. This process involves thinking about the issues and assumptions of arguments, realizing relationships between ideas and data, drawing appropriate conclusions, and evaluating the sources (ten Dam and Volman 2004). Critical thinking is a teachable skill. By developing these skills, students will be able to better evaluate and use the information they receive and carry those skills into their adult life. Critical thinking skills can be taught using better pedagogies than the ones favored by the current system of memorization. Using these pedagogies does not require a systematic overhaul of curricula, merely embedding these concepts in curricula leads to gains in critical thinking ability (Marin and Halpern 2011). However, greater gains are made when the critical thinking process is explicitly taught (Marin and Halpern 2011). In one study that focused on teaching the process of science rather than just the facts, students had better critical thinking skills and scientific literacy compared to a control class that focused only on the facts (Rowe et al. 2015).

To teach critical thinking skills, educators and students need to be empowered and supported in making this change. Educators need to be given the tools to teach these skills, be free from the fear of test scores, and give students more autonomy in the classroom. Students need to be given the freedom to seek the information they need and to interact with it on a deeper level than memorizing it. Together, students and educators can create communities of inquiry that foster critical thinking. By empowering teachers and students through education reform, we can most effectively diffuse the stigma that surrounds controversial scientific topics.

Team 2 Stance: Trust building through community outreach
Team Members: James Villegas, Emily Kraus, Michael Becker, Megan Mulcahy, Rui Chen
Faculty Advisor: Dr. Blake Wilson, Louisiana State University

Stigmas toward scientific technologies result from fear, emotion, demographics, and in-group mentality. These biases act as barriers to reason but can be overcome by trust. Outreach can build trust and promote receptive attitudes toward science.

One barrier to reason is the fear of contamination (Blancke et al. 2015). For instance, negative representations of GMOs tap into people's fears by stressing that genetic modification can contaminate the environment and the food we eat. The fear of contamination is powerful, universal, and difficult to control. Fear impedes people's ability to think rationally and affects their risk perception (Rachman 2004). Providing the public with more information on scientific technologies cannot sufficiently diminish ingrained irrational fears regarding the risks they perceive (Gorman and Gorman 2017).

Emotion is another barrier to reason. This disrupts beliefs that organisms hold an unseen, unchangeable core, determining their identity, and elicits apprehension and disgust (Blancke et al. 2015). In the case of GM food, feelings of disgust may arise when people intuitively interpret that gene modification contaminates the essence of an organism, rendering the organism impure, and no longer consumable (Blancke et al. 2015). Humans make most judgments on emotional and moral grounds not through reasoning and reflection (Haidt 2001). Results of a scientific survey show that knowledge of the technology is less important when compared to the emotional impression of the technology (Lee et al. 2005).

Cultural markers represent a third barrier to reason. In the United States the public's attitude toward science corresponds with race, class, and religion (Gauchat 2011). Of the markers investigated, religious or ideological values have the most influence on public perceptions of science (Nisbet and Goidel 2007). In general, attitudes toward science are components of broader cultural dispositions toward organized science (Gauchat 2011).

A final barrier to reason regarding GMOs and pesticides is in-group biases. People adopt the attitudes and beliefs of their societal in-groups, or an individual's closest social group (Wood 2000). Arguments against GMOs and pesticides sound more convincing when they come from a friend and/or a social group a person wants to be part of. Therefore, social values and identity serve as major anchors of public perceptions of science. In-group attitudes are virtually immune to change through personal reasoning (Haidt 2001). The majority of people are only willing to learn basic facts concerning a topic, filling in the blanks with their own ideology or religious values (Nisbet and Goidel 2007). Moreover, knowledge only explains a small amount of variance in opinions on scientific topics, while moral values, religious beliefs, and trust were stronger predictors (Nisbet and Goidel 2007). The fact is that even those scientifically trained in probability revert to the impulsive brain when it comes to making decisions regarding risk (Gorman and Gorman 2017).

Therefore, we propose that scientists must actively engage in outreach that builds trust between scientists and the community in order to overcome barriers to reason. This will promote receptiveness to factual information about controversial technologies. People tend to adopt the position of those they trust (Sloman and Fernbach 2017), and trust is a major factor in improving perceptions and acceptance of scientific technologies (Lewis and Weigert 1985, Ezezika and Oh 2012). Multiple studies have shown that trust is the most important factor in the success of agriculture and biotechnology partnerships and increased positive attitudes toward GMOs (Ezezika and Oh 2012, Marques et al. 2015).

The public should not be expected to blindly trust scientists, but to come to trust us through frequent interactions, shared information, and persuasion (Lewis and Weigert 1985). These interactions should occur via a continual outreach program, such as that maintained by the Peace Corps, which utilizes trusted individuals (Peace Corps 2006). Outreach is essential for encouraging public acceptance of controversial issues (Nisbet and Scheufele 2009), and multiple outreach programs have already been shown to benefit young students and scientists (Clark et al. 2016).

Our proposal to diffuse the stigma surrounding science is to remove the barriers to reason by building trust in science through continual outreach involving participative community engagement. Once this has been achieved the public will be more receptive to new attitudes toward technology, which will result in a decrease in stigma against scientific advancements such as GMO and pesticide technologies.

What New/Emerging Technologies Have the Potential to Revolutionize Entomology (Other Than CRISPR)?

Unbiased Introduction by Priyanka Mittapelly

Arthropod pests and disease vectors cause devastating effects worldwide and are a major challenge for human health as well as agriculture and livestock production (Giese et al. 1975). Diseases transmitted by arthropod pests and vectors negatively affect the global economy resulting in an annual loss of billions of dollars (Institute of Medicine (US) Forum on Microbial Threats 2008). Current methods to manage insect pests rely primarily on the application of broad-spectrum insecticides; however, an excess use of insecticides negatively impacts beneficial insects, increases secondary pest outbreaks, and facilitates insecticide resistance (Peter et al. 2005). In the last two decades, several technological advancements improved our understanding of insect pests to potentially help reduce the harmful effects caused to humans, agriculture, and livestock. Two emerging technologies that have a potential to revolutionize entomology and to suppress pest populations are high-throughput DNA sequencing (HTDS) and spatial repellents.

HTDS is a revolutionary tool that generates massive amounts of sequence (DNA) information from a tissue or an organism. In 1977, the first genome of single-stranded bacteriophage was sequenced using the Sanger sequencing method (Gilbert and Maxam 1973, Sanger and Coulson 1975, Sanger et al. 1977). Several techniques are now available for sequencing such as next-generation sequencing, nanopore sequencing, and single-molecule real-time sequencing (Kircher and Kelso 2010). The cost and time of these technologies have been significantly reduced compared to Sanger sequencing; however, appropriate knowledge of the sequencing platform, sources of error, and the error rate are required before using a specific technology. Most genome centers have experience in handling and analyzing the massive amounts of sequence data. HTDS technology provides a large variety of sequencing applications to researchers from various fields of study and provides reliable means to study disease vectors, arthropod pests including non-model systems. The sequencing data on insect pests will improve our understanding of structural variation, genome variation, and transcriptome characterization (Wall et al. 2009, Dalca and Brudno 2010) that can be exploited in developing potential pest control tactics.

Alternatively, the general concept of spatial repellency is to deter arthropod pests by interfering with the insect's ability to find its host, thereby preventing feeding and disease transmission (Achee et al. 2012). Developing research on novel spatial repellents provides promising alternatives to prevent the spread of mosquito-borne diseases. Unfortunately, the use of spatial repellent as a pest management approach has been neglected (Achee et al. 2012, Norris and Coats 2017). The major benefit of using spatial repellents is the use of sublethal chemicals compared to the conventional approaches (Ogoma et al. 2014, Wagman et al. 2015). It can also delay the onset of resistance to active ingredients making an effective and sustainable insecticide management approach (Achee et al. 2012). The active ingredient for the repellents is effective against many genera and species that are either insecticide susceptible or resistant. Therefore, spatial repellents can control pests in various biological, medical, and agricultural settings and can be used on a wide range of plants, animals, and microorganisms. The major challenge for a spatial repellent as a marketable product will depend on scientific, regulatory, and social constraints.

Data from HTDS provide a strong understanding on different aspects of pest biology and spatial repellents are a novel approach to control arthropod pests. Due to the importance of HTDS in arthropods belonging to diverse fields and the sublethal activity of spatial repellents, both HTDS and spatial repellents can provide a reliable method to control insect disease vectors and arthropod pests. Understanding the biology of arthropod pests and exploiting the knowledge to suppress pest populations will improve health and safety of humans, quality and yield of important agricultural crops, and the overall global economy.

Team 1 Stance: High-throughput DNA sequencing

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HTDS is revolutionizing entomology more than any other technology, excluding CRISPR. HTDS technologies like Illumina, SMRT, and nanopore sequencing yield high-quality sequence data (millions–trillions of reads in one instrumental run; Levy and Myers 2016) from fresh or preserved organisms in a quick, inexpensive manner. HTDS has dramatically decreased the cost and time required for sequencing. As the cost of sequencing a genome has dropped from billions of dollars to less than $1,000 (Levy and Myers 2016), an ever-increasing number of insect genomes have been obtained. In 2000, *Drosophila melanogaster* (Meigen) (Diptera: Drosophilidae) was the only completed insect genome. As of June 2017, 353 arthropod genomes have been sequenced (Fuentes-Pardo and Ruzzante 2017). Applications of HTDS are wide-ranging, from sequencing complex genomes, to transcriptomes, to degraded DNA, and will revolutionize research in all subject sections of ESA: Systematics, Evolution, and Biodiversity (SysEB); Medical, Urban, and Veterinary Entomology (MUVE); Physiology, Biochemistry, and Toxicology (PBT); and Plant-Insect Ecosystems (PIE).

Perhaps most obvious are the applications of HTDS to SysEB. HTDS has improved resolution of insect phylogenetic relationships and facilitated investigation of long-standing evolutionary hypotheses (Misof et al. 2014, Blaimer et al. 2015, Yeates et al. 2016, Piekarski et al. 2018). Furthermore, HTDS has improved our ability to sequence specimens from natural history collections (Blaimer et al. 2016) and promoted comparative genomic studies of morphological, behavioral, and ecological evolution (Zhan et al. 2014). This technology also allows for quick, accurate species identification (Kress et al. 2015), which decreases time and labor associated with sorting bulk samples and morphological identification (Chimeno et al. 2018), and permits entomologists to better answer questions about community ecology, (Kress et al. 2015, Kocher et al. 2017, Carew et al. 2018), species interactions (Šigut et al. 2017), and conservation biology (Sherkow and Greely 2013, Fuentes-Pardo and Ruzzante 2017).

HTDS can also advance our research related to MUVE. HTDS has allowed us to improve vector monitoring and understanding of vector capacity by providing new means to identify genetic components of vector competence (Nevoa et al. 2018), monitor pathogen prevalence in vectors (Batovska et al. 2018), and track genetic variation of pathogens (Miles et al. 2017, Dumonteil et al. 2018). Additionally, HTDS makes possible not only genetic tracking of pest outbreaks to identify outbreak origins (Dupuis et al. 2018), but also allows us to identify, monitor, and predict insecticide resistance (Miles et al. 2017, Clarkson et al. 2018, Dada et al. 2018).

In PBT, HTDS has been used to identify the genetic mechanisms underlying phenotypic plasticity in insects such as ants (Gospocic et al. 2017) and gregarious locusts (Bakkali and Martín-Blázquez 2018). It has also been used to investigate basic insect biology, such as studies of genes involved in vision, pesticide resistance, and digestion (Benoit et al. 2016, Dada et al. 2018). In addition, HTDS is being utilized to identify and characterize novel viruses and microorganisms in insects (Greay et al. 2018, Schoonvaere et al. 2018), and to identify new resources for genetic pest management of invasive species (Harvey-Samuel et al. 2017).

Finally, HTDS techniques have advanced PIE by allowing more robust descriptions of plant–insect interactions which have subsequently led to novel pest management strategies. Such advances include the characterization of insect-vectored plant pathogens (Badial et al. 2018), identifying the role insect microbiomes play in phytochemical degradation (Ceja-Navarro et al. 2015), and improvements in monitoring invasive species establishment (Brown et al. 2014). Additionally, HTDS facilitates the creation of more robust trophic interaction models through sequencing of the species and substances such as honey and pollen (Lefort et al. 2017, Derocles et al. 2018, Utzeri et al. 2018).

HTDS technologies are continuously improving, and new, innovative methods of using them are constantly being discovered. Their utility is certainly not limited to entomology, either, as they are being adopted in some way, shape, or form in almost all fields of biology. For all these reasons and many more, we believe that the advent of HTDS technologies will be viewed as a crucial breakthrough in all major areas of the entomological sciences.

Team 2 Stance: Revolutionizing entomology with spatial insect repellents

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As the global population increases, food security and disease prevention become more challenging (Beddington 2010). Insect pests threaten human health by vectoring the pathogens responsible for diseases such as dengue, malaria, and Zika. Additionally, insects attack livestock and damage crops, causing billions of dollars in yield loss (Achee et al. 2012, Zhu et al. 2015). Current management programs rely heavily on insecticides, which, although effective, can have negative impacts on nontarget organisms, human health, and the environment while potentially losing efficacy as pests develop resistance (Achee and Grieco 2012, Achee et al. 2012, Deletre et al. 2013). Spatial insect repellents are an alternative, revolutionary method that can protect human health and food supplies with fewer negative impacts.

Spatial insect repellents interfere with an insect's ability to find and feed on hosts, often by binding to sensory receptors associated with these functions (Bohbot et al. 2014, Debboun et al. 2014). Spatial repellents have been widely studied in relation to controlling mosquitoes, which remain the greatest threat to humans in many countries (Buhagiar et al. 2017). While insecticide-treated bed nets provide significant protection to people as they sleep, spatial repellents can be integrated into current management strategies to provide additional protection within homes and communities during daily activities (Boonyuan et al. 2017, Charlwood et al. 2017). For example, clip-on spatial repellent devices are able to deter several mosquito species (Dame et al. 2014). Additionally, a variety of novel synthetic and naturally derived compounds are being investigated as potential repellents against disease-vectoring insects, and have been shown to be highly effective in laboratory tests, with some demonstrating high potency in the field (Moore et al. 2007, Achee et al. 2012, Chauhan et al. 2012, Deletre et al. 2013, Bohbot et al. 2014, Ogoma et al. 2014, Syafruddin et al. 2014, Obermayr et al. 2015, Bibbs and Kaufman 2017, Boonyuan et al. 2017, Liverani et al. 2017, Masalu et al. 2017, Benelli and Pavela 2018, Kröber et al. 2018). Moore et al. (2007) provided evidence of repellents that reduced landings from malaria vector, *Anopheles darlingi* (Meigen) (Diptera: Culicidae), by >95% across field sites in Peru and Guatemala. Results from field trials in other parts of the world were similar (Chauhan et al. 2012, Syafruddin et al. 2014, Liverani et al. 2017, Masalu et al. 2017). These examples demonstrate that spatial insect repellents are effective emerging new tools for preventing the spread of infectious diseases in high-risk communities. With continued research, more potent repellents can be characterized, and their use could increase within the next decade.

There is also a rising need to protect crops and livestock from insect pests, especially as demand for meat and crop production is expected to increase by 85% and 50%, respectively (Beddington 2010). Over 40% of global crop yield loss is due to insect damage (Beddington 2010) and biting flies of livestock cause billions of dollars in losses (Zhu et al. 2015). Spatial repellents as alternatives to broad-spectrum insecticides can reduce biting fly oviposition by >90% in livestock barns (Baldacchino et al. 2013, Zhu et al. 2015). Spatial repellents have also been effective in food packaging facilities (Licciardello et al. 2013, Olivero-Verbel et al. 2013). In agriculture, identified repellent compounds and technology have successfully repelled specific crop pests (Zhang et al. 2013, Zhan et al. 2014, Rashid et al. 2017). For example, Zhan et al. (2014) demonstrated that eight compounds repelled the brown marmorated stink bug, an invasive crop pest. These compounds can be used in push-pull management strategies, where the repellents will 'push' pests away from crops, and attractants will 'pull' them toward a trap crop (Cook et al. 2007, Khan et al. 2016).

Spatial insect repellents are economically and culturally feasible to implement. Moore et al. (2007) estimated the annual cost of conventional malaria treatment in Latin America was $250 per person. The spatial insect repellents used in their field trials would cost $5 per person annually, a savings of 98%, making malaria prevention more affordable (Moore et al. 2007). Surveys found that spatial insect repellents were more accepted than other control measures in rural Cambodian and Tanzanian communities, with >96% indicating they would use the spatial repellents again (Liverani et al. 2017, Masalu et al. 2017).

Spatial insect repellents are not only effective, but more affordable, culturally accepted, and safer than conventional methods. With technology continuing to advance, new types of spatial insect repellents are being developed, i.e., ultrasonic vibration (Rashid et al. 2017). The development of novel spatial insect repellents will quickly revolutionize the field of entomology by providing an alternative to insecticides within a decade. Use of spatial insect repellents would address pressing issues of global health and food security, and thus save countless lives otherwise lost to disease and hunger.

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