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Review

Synergisms in Science: Climate Change and Integrated Pest Management Through the Lens of Communication—2019 Student Debates

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Abstract

Every year, the Student Debates Subcommittee (SDS) of the Student Affairs Committee (SAC) for the annual Entomological Society of America (ESA) meeting organizes the Student Debates. This year, the SAC selected topics based on their synergistic effect or ability to ignite exponential positive change when addressed as a whole. For the 2019 Student Debates, the SAC SDS identified these topic areas for teams to debate and unbiased introduction speakers to address: 1) how to better communicate science to engage the public, particularly in the area of integrated pest management (IPM), 2) the influential impacts of climate change on agriculturally and medically relevant insect pests, and 3) sustainable agriculture techniques that promote the use of IPM to promote food security. Three unbiased introduction speakers gave a foundation for our audience to understand each debate topic, while each of six debate teams provided a strong case to support their stance or perspective on a topic. Debate teams submitted for a competitive spot for the annual ESA Student Debates and trained for the better part of a year to showcase their talents in presenting logical arguments for a particular topic. Both the debate teams and unbiased introduction speakers provided their insight toward a better understanding of the complexities of each topic and established a foundation to delve further into the topics of science advocacy and communication, climate change, and the many facets of integrated pest management.

Key words: agricultural entomology, vector ecology, environmental impact, vegetable crop pest, vector-borne pathogen

Debates Introduction

The Student Debates Subcommittee (SDS), composed of a subset of members from the annual Student Affairs Committee (SAC), identifies topics of interest and organizers ESA's Student Debates. The 2019 debate topics were selected for their ability to ignite and inspire advocacy in science and to promote greater discussion and action from the scientific community. The 2019 Student Debates were held during the Entomological Society of America (ESA) Annual Meeting in St. Louis, MO, with the meeting theme of 'Advocate Entomology'.

Student members of the ESA community submitted for competitive slots to participate in the student debates. Debates teams worked for the better portion of a year to prepare, research, and write for a debate topic. During the debates, team members showcased their critical thinking skills and knowledge of each topic through summaries delivered at the beginning of each debate and on-the-spot responses to rebuttals and judge questions.

The 2019 ESA Student Debate unbiased introductions and topic summaries are provided in this article. The debate topics included:

1) How can scientists better communicate with the public to get them more engaged in integrated pest management (IPM)?
2) What is the most influential impact of climate change on entomology?
3) Sustainable agriculture (such as polyculture/farmscaping/push–pull) is the best approach to farming when incorporating IPM techniques (pro/con).

How Can Scientists Better Communicate With the Public to Get Them More Engaged in IPM?

Unbiased Introduction by Lina Bernaola

Scientists play a role in informing the public at large on scientific topics. Engaging friends and neighbors outside of formal class room settings is a critical task for the scientific community that can raise awareness of challenges from climate change to agricultural practices such as integrated pest management (IPM). There is a need to get more people involved in these issues and this can be done in a number of ways such as by reading scientific journals or by following social media influencers who focus on scientific topics. In this debate, we consider two approaches to effectively communicating IPM to the public: improving scientific literacy and enhancing the public's interest in science through popular social media platforms.

Scientific literacy begins at a young age in school, and it helps shape the minds and critical reasoning abilities (Lawson 2009) of everyone as they mature and join society. Training in scientific literacy does not need to stop at a given age though; lifelong learning is beneficial for improving scientific understanding and combating disinformation. If critical thinking and scientific training were more prevalent, the understanding of food production and the use of agrochemicals, with all of their environmental rewards and risks (Cui and Shoemaker 2018), would be more widespread. If the hype of noncredible sources of information on pest management practices were drowned out by reputable, scientifically backed sources, then public discourse could be more productive. The availability of quality sources is present, but the challenge for building scientific literacy (Miller 2001, Liu 2009) is having the general public (all individuals not trained in a specific field or discipline that is being discussed) sort through and find the best research. From these quality sources, the general public reader must fully comprehend material that is often filled with technical terms or undefined scientific jargon. The current perception of many scientists is that a lack of qualified individuals (Munir 2017) engaging in science communication leads to an opportunity for pundits to speak their opinions, instead of facts, on important matters of environment, science, and policy. There is an uphill battle for teaching and public engagement, where only a few people (less than 5% according to Wilen et al. 2011) are even aware of IPM. In the study by Wilen et al. (2011), only more relatable terms such as 'Responsible Pest Management' were in the vocabulary of those interviewed. An increase in defining technical terminology in scientific articles as well as a reduction of technical jargon in science communications (such as popular science articles and blogs) could enhance the accessilbility of content, as it would lower the technical complexity and literacy required to access information from credible sources. In consideration of this, some respected journals and associations, such as Frontiers for Young Minds, the Entomological Society of America, the American Association for the Advancement of Science, and the Environmental Protection Agency, accommodate many different groups and ages by using many different groups and ages by using more accessible concepts and platforms (i.e., infographics, blogs, visual abstracts, non-technical summaries) concepts to communicate science.

Enhancing scientific literacy of IPM through scientific articles is only one aspect, though; another approach to informing IPM is by actively reaching out to the public in ways that genuinely capture attention. Interactive communication is one of the key elements to connecting with audiences (Stocklmayer et al. 2001) and social media excels in this regard. The media platforms developed in the past few years can give scientists a megaphone (Osterrieder 2013) to speak about IPM while providing nearly immediate feedback with counts of views, likes, and comments. For example, Twitter is one of the most popular social media outlets (Clement 2019) that uses hash tags to allow people to connect with other like-minded individuals. For example, using a hashtag such as #scicomm allows those interested in communicating science to come together easily and share ideas. Accurate science communication content from experts and communication specialists that comes in easily accessible formats could be the best method to get more people interested in agricultural discussions.

Whether through trusted literature or informative social media, science communication is on the rise. Understanding science is a shared responsibility between the scientific community and the general public. Therefore, the style and content of communication must be tailored to the intended audience to most effectively empower people with knowledge. Expanding and facilitating an audience's curiosity in IPM will help engage food producers and policy makers alike in increasingly constructive ways.

Team 1 Stance: Scientists Can Use Social Media to Better Communicate With the Public and Get Them More Engaged in IPM

Team Members: Chris McCullough, Jennie Wagner, Max Ragozzino, Morgan Roth

Faculty Advisor: Dr. Doug Pfeiffer

Academic Institution: Virginia Polytechnic Institute and State University

Today's scientists face the struggle of communicating their research. Although scientists work with the goal of publishing in scientific journals, this platform is ill-suited and inaccessible to a general audience. Scientists tend to view the public as ignorant receptacles for their research rather than as individuals who will view this research through the lens of their education, past experiences, and biases (Ko 2016). These same scientists may then be surprised when the general public ignores their research and finds more accessible information through social media. Although many scientists desire to communicate with the public via social media (Howell et al. 2019), an us-versus-them mentality and lack of social media knowledge can hinder scientists in these efforts; however, if utilized properly, social media can be the greatest asset scientists have in communicating their research. To solve the problem of improving public engagement in IPM, awareness through social media is the solution. Social media is an easy and cost-effective way to reach an enormous target audience, allowing for easy measurements of engagement and starting a vast network of information dissemination among the public.

It is estimated that 75% of adults in the United States use at least one form of social media (AAAS 2019), and the average American uses three social media platforms (Smith and Anderson 2018). Of the various social media platforms available, Facebook has 2.4 billion users, YouTube has 3 billion, Instagram has 1 billion, and Twitter has 330 million users (Clement 2019). Millennials are the largest and most diverse demographic in the United States and are some of the most frequent users of social media (U.S. Census Bureau 2015, Smith and Anderson 2018). Aside from reaching unprecedented numbers of people, social media communication gives the person sharing the information the ability to target a specific audience and get precise metrics on the number of people their information is reaching (Peters et al. 2013). This helps lead to more intentional sharing of information.

Scientists can improve engagement in their research by learning simple tactics that have been shown to increase user engagement, such as word use and grammar (Hwong et al. 2017), along with presenting messages in a positive light (Mahmud et al. 2014). It is also important to remember that preference for subject matter can be overruled on social media by visual cues (Vraga et al. 2019). It is crucial for scientists to talk directly to the audience at their level, not talk down to the audience. Social media is a way for scientists to not only give information, but also receive feedback about the importance of their work. Although not every social media user will actively engage with content (i.e., like, share, retweet, or respond to a call to action), even passive engagement can advance the knowledge of viewers and may lead to action in the future (Alhayan et al. 2018).

Social media use is only continuing to grow and if scientists want to have a voice for IPM, they need to learn to dialogue with the general public through social media. By reducing jargon and sharing their work in relatable ways, scientists can build public trust (Haunschild et al. 2019). Rather than talking down to the public, social media use can allow scientists to unite with the public in furthering issues like IPM use, which will be mutually beneficial and only require effective communication to be properly understood.

Team 2 Stance: Improving Science Literacy Among the Public Is the Best Way to Get Them More Engaged in IPM

Team Members: Leslie Aviles, Zhilin Li, Forest Huval, Manoj Pandey (LSU2)
Faculty Advisor: Dr. Blake Wilson
Academic Institution: Louisiana State University

The Rise in popularity of organic food and an interest in food labeling indicates that the public is interested in knowing more about the processes associated with food production, particularly genetically modified organisms (GMOs), pesticide use, and IPM as pesticide use, and IPM (Hallman et al. 2002, Howard 2005). However, studies show that the public remains generally uninformed about IPM (Schoelitsz et al. 2019). Surveys of the American public demonstrate that less than a quarter of people felt they knew how their food was produced (Howard 2005). The appeal of organically produced food and aversion to pesticides among the public is based heavily on misconceptions associated with nutrition, agrochemical use, and health risks (Trewavas 2001, Saba and Messina 2003, Campbell et al. 2014). Health remains the primary motivational factor for organic food preference (Lockie et al. 2002, Hughner et al. 2007) when, in fact, there is little evidence that organic food is safer or more nutritious compared with conventionally grown food (Magkos et al. 2003, Williamson 2007, Miller and Cohrssen 2018). Public perceptions toward GMOs are reported to be similarly ill-informed (Oeschger and Silva 2007). Survey results reviewed by Marris (2001) demonstrate that the majority of the public was unsure whether tomatoes contained genes. GMOs are also frequently erroneously associated with unrelated food-safety issues such as mad cow disease (Marris 2001). Extensive study of consumers through field and laboratory experiments, in addition to panel surveys, found that preference for non-GM-labeled food is rooted in moral opposition rather than a scientific basis (Hingston and Noseworthy 2018).

These public attitudes are being reinforced through the prevalence of misinformation and propaganda spread by nonreputable sources or 'fake news'. This effect has been exacerbated by the public's growing dependence on online sources and social media for news and information. A survey in 2018 found that about 68% of American adults at least occasionally get news from social media, despite over 50% of those respondents admitting they expect inaccuracy from online sources (Smith and Anderson 2018). In recent years, fake news has become immensely prevalent on social media. During the 5 mo preceding the 2016 U.S. election, 25% of tweets spread fake or extremely biased news (Bovet and Makse 2019). Researchers also found fake news spreads significantly faster and farther than the truth (Vosoughi et al. 2018), which is likely to result in a deeper influence on the public when compared with credible information. Fake news strongly influences opinions because it frequently appeals to emotional biases and cultural beliefs (Yap et al. 2018). These opinions are reinforced by the tendency of people to seek information that supports their currently held beliefs rather than to look for objective sources (Nickerson 1998).

Scientifically backed information about IPM is readily available online through works of Extension services and other organizations (Bajwa and Kogan 2006, Isard et al. 2006, Giles and Walker 2009), but is not accessed by many members of the public. Efforts by cooperative Extension services, Environmental Protection Agency (EPA), and other organizations to provide information to the public regarding IPM and pesticides (Cooper and Dobson 2007, WHO 2013) are often overshadowed by the impacts of fake news. This is because scientific literacy is needed to identify, locate, and understand credible sources of information, which is reported as deficient in much of the public population (Metzger 2007). For example, over two thirds of college students have problems evaluating tweets and judging website credibility (Donald 2016).

Improving science literacy among the general public will allow people to distinguish fake news from reliable information, thus reducing the influence of misinformation (Lazer et al. 2018). As scientific literacy improves, public desire to understand food production and environmental risk can then be channeled toward scientifically backed sources resulting in increased engagement in IPM.

What Is the Most Influential Impact of Climate Change on Entomology?

Unbiased Introduction by Kadie Britt

Climate change is an issue faced by our planet. It is not a new concept nor will it be easily resolved. Climate change impacts humans and many of the problems we are currently facing or will be facing in the future are insect related. Insects are the most diverse class of organisms on earth, having many detrimental and beneficial effects on humans and natural ecosystems, so it is no surprise that changes to insect biology and pest status are considered in the realm of global environmental change (May and Beverton 1990).

A major consequence of climate change to entomology is shifting climate regimes in most areas of the world and, as a result, insect species can now occupy areas of the world previously outside their habitat range (Falt-Nardmann et al. 2018). This has major implications for crop, human, and animal protection worldwide. With the current change in climate, crops are at greater risk of plant stress and insect damage, whereas growers face greater potential economic loss (Kistner 2017). Medically important insects are able to remain viable across greater distributions for longer durations of time, heightening pathogen transmission potential. Climate change is currently affecting and will continue to affect every person throughout earth.

Due to rising temperatures, numerous crop pests now occupy areas farther north than their traditional range of distribution (Bebber et al. 2013). Winter die-off of pest insects is a usual form of natural population maintenance (Kistner 2017). However, many locations at higher latitudes are experiencing warmer winter temperatures, leading to higher densities of emerging pest insects that will reproduce, feed on, and damage crops for a longer period (Bale et al. 2002). Related, shifts in insect life cycles due to increased temperatures are leading to earlier emergence and geographic distribution of overwintering insects (Bell et al. 2015). Climate change predictions show that current multivoltine insects will have an even greater number of generations per year, leading to greater economic damage and ultimate crop yield loss (Yamamura and Kiritani 1998, Tobin et al. 2008, Ziter et al. 2012). Although we may see a decrease in suitable habitat for several pests in more southern regions (i.e., equatorial areas) due to increased temperatures, we could see a drastic increase in range expansion of crop pests in more northern regions due to warming climates making previously unsuitable habitat more favorable (Altizer et al. 2013, Mordecai et al. 2017).

Not only will insect density, phenology, and crop and human risk to insect pests be altered, but efficacy of pest control strategies will likely decrease, or at least be altered (Harrington et al. 2001). Consider beneficial insects—similar to the way pest insect density and phenology change, beneficial insect density and phenology will be altered and we may see lower success of pest management by certain beneficial insect species (Harrington et al. 1999). Considering chemical control, days suitable for spraying will increase in current dry areas and decrease in wetter areas (Harrington et al. 2001). Toxicity of active ingredients may also lessen due to environmental conditions altering chemical stability or volatility through changes in pest behavior or susceptibility (Harrington et al. 2001).

Continued changes in climate will lead to altered habitat suitability for pathogen transmitting organisms or vectors (Tjaden et al. 2018). Increased winter temperatures may lead to greater overwintering success of insect vectors. Increased precipitation due to climate change could lead to increased habitat availability of insect vectors due to increased soil moisture, humidity, and natural pond availability (Tjaden et al. 2018). Although extreme flooding events can lead to the destruction of vector habitats through flushing of stagnant water bodies, it can simultaneously create new breeding grounds when water recedes (Ahmed and Memish 2017).

Team 3 Stance: Global Climate Change Threatens Human Existence by Enhancing Vector-Borne Pathogens

Team Members: Benjamin Lee, Abigail Hayes, Abigail Cohen, Megan Asche, Adrian Marshall
Faculty Advisor: Dr. David Crowder Academic Institution: Washington State University

Vector-borne pathogens (VBPs; those transmitted from a carrier organism to a host) have been a persistent threat throughout human history, and despite advances in vector control and medical interventions, they continue to pose an insurmountable danger to humans globally. Perhaps the most famous and severe historical pandemic, the flea-vectored *Yersinia pestis* (Lehmann and Neumann 1896, van Loghem 1944; Enterobacteriales: Enterobacteriaceae) caused a massive Bubonic Plague outbreak in the Middle Ages, killing over 25 million people and irrevocably stalled the development of the European continent (Lounibos 2002). Despite steady advancements in disease management, this burden persists, with 216 million cases of malaria reported in 2016 and a 30-fold increase in global incidences of Dengue fever over the past 50 yrs, rising to nearly 390 million reported infections annually (Caminade et al. 2019). Here we argue that climate change will magnify the existing danger we face to a catastrophic level by increasing the range and abundance of the most prominent vectors of human pathogens.

As global temperatures rise to projected levels, environments will almost universally become more suitable for the most dangerous arthropod vectors. Ixodid ticks (arachnids often studied by vector biologists and public health entomologists) are vectors of pathogens such as strains of Borrelia (Swellengrebel 1907; Spirochaetales: Spirochaetaceae) that cause Lyme disease and other emerging infectious diseases, will reproduce twice as fast under projected temperatures in North America (Ogden et al. 2008, 2014). Dipteran vectors, such as mosquitoes and biting midges, which transmit pathogens including the emerging Dengue, Zika, and Chikungunya viruses, respond more rapidly to environmental changes, resulting in unpredictable population booms and epidemic disease outbreaks as climate variability increases (Ogden and Lindsay 2016). Expansions in geographic range with suitable climates for many vector species will also increase, overlapping with the world's most densely populated regions (Caminade et al. 2019). Even in intermediate climate scenarios, this results in an estimated 500 million more people at risk of several *Aedes*-borne, transmitted by *Aedes* (Meigen 1818; Diptera: Culicidae) mosquito species, viruses in the next 30 yr (Ryan et al. 2019), with similar risk increases for tick-borne pathogens across North America and Europe (Leighton et al. 2012, Medlock et al. 2013).

Exacerbating the danger of vector range expansion into densely populated areas is the inadequacy of public health responses to VBPs. Vector control efforts are difficult to adapt to novel pathosystems (or parasite and pathogen ecosystems) and have had limited success in reducing VBP incidence (Gage et al. 2008); studies evaluating their efficacy often ignore emerging concerns such insecticide resistance (Bowman et al. 2016). Newly exposed human populations are also more susceptible to VBP outbreaks, and we have historically failed to adequately vaccinate populations even when vaccines are highly effective and cheaply produced (Shearer et al. 2017). Even when vaccines are available, global shortages have already occurred during severe outbreaks (Walldorf et al. 2017), disproportionately affecting countries with low gross domestic products or GDP (Githeko et al. 2000). Unpredictable vector range expansions from increased climate variability will make predicting outbreaks and maintaining vaccine stockpiles even more difficult. Worryingly, the possibility of unidentified VBPs surfacing is increasing as greater numbers of potential vector species and unidentified pathogens expand their ranges into densely populated regions (Weaver and Reisen 2010).

With massive increases in vector populations, this puts human populations at greater disease risk, and the damage to humanity could be catastrophic. Over the next 50 yrs, hundreds of millions of people may be exposed to VBPs for the first time. This will result in both deaths and an increased prevalence of chronic, debilitating diseases from Chikungunya, Dengue, and Zika viruses, the damage from which cascades to future generations (Huang et al. 2019, Ryan et al. 2019). Simultaneously afflicted by other climate-induced catastrophes such as extreme weather events and forced migration, there will be limited capacities for a global public health response (Black et al. 2011). The ubiquitous increases in range and abundance of vectors of pathogens resulting from global climate change therefore represent an immeasurable danger to humanity and the most pressing issue for entomologists to investigate.

Team 4 Stance: Cascading Effects of Climate Change on Agricultural Insect Pest Distribution, Abundance, and Food Production Are the Most Influential Impact to Entomology

Team Members: Hannah Quellhorst, Valerie Nguyen, Rachel Wilkins, Jackie Maille

Faculty Advisor: Dr. Rob Morrison

Academic Institution: Kansas State University

Food security is a basic human right (United Nations 2010). However, nearly 1 billion people are suffering or have been devastated by hunger, amounting to one in nine people; 2 billion more are food insecure or lacking in reliable access to affordable and nutritious food (United Nations 2010). With the global population reaching 9.8 billion people by 2050, food production must increase by 70% (FAO 2009). However, current yield increases are insufficient to reach even a 50% rise by midcentury (Ray et al. 2013). This is compounded by insect pests, which cause roughly 18% crop loss pre-harvest and up to 75% post-harvest (Oerke 2006, Wacker 2018).

The impacts of global climate change (GCC) on pestiferous insects are multifactorial. GCC will cause insect populations to disperse to new areas, driving them poleward into ranges where ecosystems are poorly adapted to cope with invaders (Bale et al. 2002, Aljaryian and Kumar 2016, Arthur et al. 2019). Climate change will also affect dispersing propagule pressure (Ward and Masters 2007). Together, invasive insect pest species are annually responsible for up to $120 billion in economic damage in the United States alone (Pimentel et al. 2005).

The Intergovernmental Panel on Climate Change (IPCC) predicts a 1.5°C increase in global surface temperature and increasing differences in precipitation between wet and dry regions (Aregbesola et al. 2019). Global yield losses are projected to increase by 10–25% with every degree of surface warming (Deutsch et al. 2018). These higher average temperatures will produce more insect generations each year as well as higher abundances per generation (Tobin et al. 2008, Estay et al. 2009, Choudhary et al. 2019). Greater overwintering survivorship will contribute to increasing insect pressure (Takeda et al. 2010, Gu et al. 2018). Longer growing seasons (Bale et al. 2002, Ju et al. 2017) will extend growth and reproductive periods of insects in the northern regions (Bale et al. 2002, Takeda et al. 2010). Insects capable of traveling poleward will bring associated plant pathogens with them, impacting wheat, barley, and oilseed rape (Roos et al. 2011, Trębicki et al. 2015, Aregbesola et al. 2019, Tian et al. 2019).

GCC will affect nearly every aspect of insect pest management, including chemical and biological control. There are now nearly 600 documented cases of pesticide resistance in arthropod pests (Maino et al. 2017). Longer growing seasons under GCC will decrease pesticide efficacy and increase pesticide application costs (Koleva and Schneider 2009, Deutsch et al. 2018). Higher voltinism, or number of insect generations per season, will increase development of resistance, whereas warmer temperatures will allow insects to better detoxify pesticides through increased metabolism, making insecticides less effective (Maino et al. 2017, Matzrafi 2019). Ultimately, these effects will hinder IPM tactics (Oerke 2006, Maino et al. 2017, Taylor et al. 2018, Matzrafi 2019). GCC will have a negative impact on biological control, causing asynchrony between hosts and parasitoids, while lowering the efficacy of pesticide-free management techniques (Chidawanyika et al. 2019). Phenology changes and environmental cues altered by GCC will create plant–pollinator mismatch, ultimately reducing the production of seed and fruit commodities (Forrest 2015).

Changing cropping systems requires high initial investments in new equipment and associated inputs (Roesch-McNally et al. 2018). Existing policy and economic incentives discourage cropping system diversity in the U.S. corn belt (Roesch-McNally et al. 2018). Despite the efforts at crop diversification (Roesch-McNally et al. 2018) and promise of genetically modified crops compensating for abiotic stresses (Paarlberg 2001), the effects of GCC will cause unacceptable losses at a time when productivity must increase (Deutsch et al. 2018, Tito et al. 2018). Consequently, the most influential impact of climate change on entomology is the increased distribution and abundance of insects, which will have devastating effects on global agricultural production.

Sustainable Agriculture Is the Best Approach to Farming When Incorporating IPM Techniques

Unbiased Introduction by Rachel K. Skinner

The Green Revolution of the mid-20th century ushered in an age of unprecedented food crop production, in part to fertilizers, pesticides, and genetic crop improvement (Pingali 2012). These improvements were a great boon for human nutrition and helped fuel a human population that is projected to exceed 10 billion by 2100 (United Nations 2019). However, there is increasing recognition of the detrimental effects that modern agricultural practices can have on ecological systems and ecosystem services (Power 2010, Foley et al. 2011). The negative impacts of agriculture on habitat loss (Ramankutty et al. 2008), biodiversity (Kremen and Miles 2012), water quality (Foley et al. 2005), and nutrient cycling (Power 2010), as well as agriculture's contribution for 10–12% of anthropogenic greenhouse gas emissions (Smith et al. 2014), have led to considerable interest in identifying agricultural practices that can mitigate environmental degradation (Tilman et al. 2011).

IPM techniques that aim to reduce reliance on pesticides, maintain biodiversity in agroecosystems, and reduce the ecological impact of agriculture are methods of lessening agriculturally driven environmental harm and have been successfully adopted in many crop systems (Pedigo 1989, Higley and Wintersteen 1996, Barzman et al. 2015, Farrar et al. 2016). Since its original inception (Stern et al. 1959), IPM has expanded to include all aspects of plant protection and supports simultaneous use of multiple pest management tactics such as pest population suppression via tilling techniques and resistant plant cultivars, protection of beneficial organisms, application of targeted chemical controls, and pesticide resistance management (Barzman et al. 2015), as well as considering pest ecology and evolution in management strategies (Peterson et al. 2018). However, there is disagreement over whether such methods are best used in combination with conventional or sustainable agricultural practices, such as polyculture, farmscaping, and push/pull systems, due to the need to balance environmental concerns with the nutritional requirements of an expanding population.

Sustainable agriculture emphasizes the importance of crop production methods that are ecologically, economically, and socially sound and that promote the long-term maintenance of agricultural productivity (Neher 1992). However, some sustainable farming practices can result in potentially persistent yield gaps compared with conventional agriculture (Ponisio et al. 2015, Schrama et al. 2018) and may face economic, informational, social, and political barriers to extensive adoption by farmers (Wezel et al. 2014, Lefebvre et al. 2015, Carlisle 2016, Carlisle et al. 2019). There has also been difficulty in establishing quantitative measures of sustainable farming outcomes, meaning that the actual environmental impact of practices regarded as sustainable can be difficult to assess (Hansen 1996, Hunter et al. 2017).

In contrast, conventional farming includes practices such as large-scale monoculture cultivation and relies heavily on external energy and nutrient inputs, pesticide use, and agricultural technology and agribusiness (Gold 1999). Such methods have drastically increased crop yields per unit of farmed land and improved human nutrition across the globe (Pingali 2012). Expansion of high-yield farming could potentially help prevent habitat loss by reducing the total land area needed for food production (Phalan et al. 2011a), but prevention of the other negative environmental impacts described above remains to be extensively addressed.

The principles of IPM as currently conceptualized are well-aligned with sustainable farming practices (Peterson et al. 2018), but it is also possible to deploy IPM strategies while maintaining conventional agriculture's high-yield capabilities (Farrar et al. 2016) and, thus, the best way to implement IPM practices remains debated. The consequences to human nutrition and health, short- and long-term environmental impacts, and technological, social, and political viability of alternative agricultural practices must all be carefully considered in decisions about the future of farming.

Team 5 Stance: Sustainable Agriculture such as Polyculture, Farmscaping, and Push–Pull Is the Best Approach to Farming When Incorporating IPM Techniques (Pro Position)

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Faculty Advisor: Dr. Rachel Mallinger
Academic Institutions: [1]University of Florida, Gainesville, [2]Purdue University, [3]Michigan State University

Sustainable agriculture is the best approach to farming when implementing IPM. IPM is a decision support system that applies a holistic ecological, economic, and social approach to pest management. To achieve this, sustainability is championed as a crucial and foundational element of IPM (Stern et al. 1959). The integrative agroecological approach of sustainable agriculture closely parallels these guiding philosophies of IPM by promoting greater long-term productivity, efficiency, and resiliency in crops using renewable inputs and a diverse array of management practices (Stern et al. 1959, Godfray et al. 2010, Peterson et al. 2018). Therefore, sustainable agriculture and IPM provide the best strategy for achieving global food security. Several sustainable agricultural practices, including crop rotation and cover crops, have been successfully implemented on a large scale as measures for improving ecosystem services and reducing pest pressure. In contrast, the conventional agricultural model prioritizes present-day yield and profit maximization through highly intensive, nonrenewable large-scale inputs on monocultural cropping systems (i.e., growing only one crop type) that impair ecosystem services, exacerbate pest outbreaks, and introduce production volatility (Lockeretz 1988, Kremen et al. 2012, Wilson and Daane 2017). This system of farming has led foundational individuals in IPM research to argue that IPM has deviated from its original principles, thereby reducing its effectiveness (Peterson et al. 2018).

One key component of this effort to reduce volatility and inputs is the establishment of diversified agroecosystems that allow for ecologically based pest management, which takes into account ecosystem function and organism interactions (Wilson and Daane 2017). Natural enemies are one of the most effective, environmentally safe, and economically profitable methods of biological control (Van Lenteren 2012) and are a major component of IPM practices; in fact, biological control has been valued at $4.49 billion across the United States (Losey and Vaughan 2006). Diversified agroecosystems attract a variety of natural enemies while minimizing the density of host plant resources that attract pests, thereby reducing the potential for pest outbreaks (Crutsinger et al. 2006, Wilson and Daane 2017). By prioritizing long-term yields and environmental stewardship, sustainable agriculture reduces the inputs required for managing pests.

In addition to long-term production potential and ecologically based pest management, sustainable agriculture has high potential for successful implementation across the globe (Pretty et al. 2006, Wegner and Zwart 2011). Reducing volatility in yields through sustainable pest management and crop diversification is especially important for small farms, which support a third of the world's population (Wegner and Zwart 2011). In many developing countries, investments intended to jump-start large-scale agricultural growth did not return benefits to local populations (Wegner and Zwart 2011). Intensified conventional agriculture is upheld as a means of producing massive amounts of food needed for an ever-growing population, yet it often fails to meet the needs of people across the globe (Birch et al. 2011). In order to produce the food necessary to reduce this nutritional gap, the focus must shift from a Western-centric model of conventional agriculture to a sustainable agricultural model that can be sufficiently adopted across local and global levels (Pretty et al. 2006).

Sustainable agriculture is the best approach to farming when implementing IPM practices because it allows for the most thorough and effective use of all the tools in the IPM toolbox. Sustainable agricultural practices such as polyculture, farmscaping, and push–pull promote long-term profitability and landscape health over short-term practices that maximize yield through intensive inputs while reducing ecosystem services (Lockeretz 1988). The use of a multifaceted approach like IPM is improbable in a conventional system that is inherently focused on the short term. For those reasons, IPM is most effectively practiced in the context of sustainable agriculture.

Team 6 Stance: Polyculture, Farmscaping and Push–Pull Are Not the Best Approaches to Achieving Sustainable Pest Management When Farming With Integrated Pest Management Techniques (Con Position)

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Currently, there is a drive toward sustainable agricultural practices that ensure food availability despite global challenges including increasing population and rapid climate change (Birch et al. 2011, Gabriel et al. 2013). Research shows that we will need to grow 70–100% more food on less land by 2050 to ensure global food security (Tilman et al. 2011).

Proponents of small-scale agriculture, agroecology, and organic farming emphasize the flaws of intensive agriculture while ignoring the ways that modern agriculture has become more efficient and environmentally conscious (Kershen 2013, Tal 2018). Conventional does not equate to unsustainable. IPM has been used successfully on conventional farms to improve pest control whilst reducing the negative effects of agriculture on surrounding ecosystems (Gray et al. 2008). Cotton growers in Arizona successfully manage pests using large-scale IPM practices, including host plant resistance, Bt crops, and conservation biological control (Ellsworth et al. 2017). California fruit and nut farmers have improved pest management and reduced harmful pesticide applications by enhancing their monitoring programs, field hygiene, use of resistant varieties, and pest mating disruption (Farrar et al. 2016). These conventional IPM practices are the best methods for reducing crop pests and maintaining economic viability. Technological advancements in precision agriculture, plant genetics, pesticide selectivity, and energy efficiency result in fewer inputs required to maintain high-yielding agricultural systems (Savage 2014, Rehman et al. 2016, Alphey and Bonsall 2018). Pesticides like chlorantraniliprole and insect growth regulators do not negatively affect nontarget species and have decreased the reliance on broad-spectrum insecticides (Fernandes et al. 2016). Precision agriculture improves efficiency of agricultural inputs, thereby minimizing costs and mitigating environmental impacts by preventing overuse of water, fertilizer, and pesticides (Alphey and Bonsall 2018).

In contrast to conventional IPM tactics, organic and agroecological farming suffers from decreased land-use efficiency (Kniss et al. 2016), extensification (Gabriel et al. 2013), and yield gaps upwards of 20% (Kershen 2013). Intensification practices in large-scale cereal crop production, discussed above, have led to declines in agricultural land use in high-yielding North American and European countries (Ritchie and Roser 2013a, b). Conversely, regions in Africa and Asia that rely on small-scale agriculture have increased acreage used for food crops to improve productivity (Ritchie and Roser 2013a, b). Transition to small-scale farming requires up to 30% more land to produce similar caloric yields as conventional agriculture (Tal 2018). Therefore, increasing production per acre ultimately can improve sustainability by preventing agricultural encroachment on natural areas (Phalan et al. 2011b). This approach is referred to as land-sparing and is more sustainable than the land-sharing approach (integrating agriculture and natural ecosystems), which underpins agroecological practices (Green et al. 2005).

Furthermore, agroecology is knowledge intensive, resulting in poor adoption and income instability (Pannell 1999, Roesch-McNally et al. 2018). Farmers have to tailor agroecology to suit their specific farming system, requiring knowledge of complex processes such as pest population dynamics and tritrophic interactions with other species (Philips et al. 2014). Success of these practices is also highly variable in terms of effective pest management (Levine et al. 2002, Wegner and Zwart 2011, Maharjan et al. 2013, Karp et al. 2018). Farmscaping and polyculture may increase habitat diversity, but these methods do not always improve pest management and may even be detrimental. According to Moore et al. (2019), diversity achieved through intercropping and trap cropping increases predation against beneficial arthropods or attracts natural enemies away from target crops. In soybeans, farmscaping actually increased the abundance of stink bugs, as well as the prevalence of secondary pest species (Pilkay et al. 2015).

Therefore, the best method to reduce pests, maintain ecosystem services, and provide food for the expanding population is through sustainable intensification of existing agricultural land by a greater use of technology and IPM.

Debates Summary

We hope that the debate topics and stances on science advocacy and communication, climate change, and approaches to IPM in farming have expanded perspectives and sparked further discussion and interest. While the unbiased introduction speakers provided a wonderful foundation for understanding the complexity of each topic, it is important to note that these debate topics are just the beginning of a larger conversation and need further action to influence positive and successful change in these areas. This need for further conversation and analysis was highlighted by the debate teams, all of which did an excellent job in presenting arguments to address each topic area.

In addition to identifying these topic areas, the SAC SDS advocated for entomology by posting relevant content via social media using #Entsoc2019. We urge our readership to further examine each debate topic in order we urge our readership to further examine each debate topic in order to be well informed with the subject matter. It is important to remember that science advocacy and communication also encompasses extension, outreach, mentoring undergraduate student researchers, general interactions with the public, and much more. Similarly, climate change can influence many aspects of agriculture such as plant health, crop yield, and water use, while the distribution as well as virulence or potency of pathogens can complicate vector biology as our climate continues to change. Last, it is important to look further into IPM of other farming systems, such as aquaponics, greenhouse operations, or community gardens, while also taking into consideration the expansive food deserts (areas of lower socioeconomic backgrounds without access to healthy or nutritious food) that are present, even with current large-scale agricultural operations.

Although individuals and other disciplines can (and should) discuss and address the topic areas of the 2019 student debates, it is important to remember that entomology, the study of insects, is integrative and interdisciplinary. The multifaceted nature of entomology allows for innovative approaches and solutions in agriculture, urban areas, forensics, insect taxonomy, and systematics, as well as in medicine and vector biology, just to name a few. Therefore, we think that entomology is well suited to help tackle the current topic areas addressed by the 2019 student debates.

Members from each debate team worked diligently and collaboratively to form argument stances for each topic. In addition, they analyzed the information during the debates to develop logical rebuttals to support their topic. Each debate team and unbiased introduction speaker represented not only the caliber of their university, but also the caliber of the current ESA membership. We congratulate and thank all participants for their hard work.

The SAC encourages students to establish teams, including those composed of multi-university members, future Student Debates at ESA Annual Meetings. In addition, we invite the ESA membership to attend next year's sure to be riveting debates. Beyond the Student Debates, the SAC encourages the readership to advocate for science and the roles held by entomology throughout the greater global community.

Lastly, we encourage you to stay tuned for an extended discussion of the debate topics in a series to be featured in the *Annals of the Entomological Society of America*, based on the discussion and rebuttals of each debate team.

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References Cited

AAAS. 2019. Communicating science online. (https://www.aaas.org/programs/center-public-engagement-science-and-technology/communicating-science-online).

Ahmed, Q. A., and Z. A. Memish. 2017. The public health planners' perfect storm: Hurricane Matthew and Zika virus. Travel Med. Infect. Dis. 15: 63–66.

Alhayan, F., D. Pennington, and S. Ayouni. 2018. Measuring passive engagement with health information on social media. *In* Proceedings, 2018 21st Saudi Computer Society National Computer Conference. IEEE (Institute of Electrical and Electronics Engineers), Riyadh, Saudi Arabia.

Aljaryian, R., and L. Kumar. 2016. Changing global risk of invading greenbug *Schizaphis graminum* under climate change. Crop Prot. 88: 137–148.

Alphey, N., and M. B. Bonsall. 2018. Genetics-based methods for agricultural insect pest management. Agric. For. Entomol. 20: 131–140.

Altizer, S., R. S. Ostfeld, P. T. Johnson, S. Kutz, and C. D. Harvell. 2013. Climate change and infectious diseases: from evidence to a predictive framework. Science 341: 514–519.

Aregbesola, O. Z., J. P. Legg, L. Sigsgaard, O. S. Lund, and C. Rapisarda. 2019. Potential impact of climate change on whiteflies and implications for the spread of vectored viruses. J. Pest Sci. 92: 381–392.

Arthur, F. H., W. R. Morrison, and A. C. Morey. 2019. Modeling the potential range expansion of larger grain borer, *Prostephanus truncatus* (Coleoptera: Bostrichidae). Sci. Rep. 9: 1–10.

Bajwa, W. I., and M. Kogan. 2006. Internet-based IPM informatics and decision support. *In* E. B. Radcliffe, W. D. Hutchison, and R. E. Cancelado (eds.), Radcliffe's IPM world textbook. University of Minnesota, Department of Entomology, University of Minnesota, St. Paul, MN. https://ipmworld.umn.edu/bajwa:.

Bale, J. S., G. J. Masters, I. D. Hodkinson, C. Awmack, T. M. Bezemer, V. K. Brown, J. Butterfield, A. Buse, J. C. Coulson, J. Farrar, et al. 2002. Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. Global Change Biol. 8: 1–16.

Barzman, M., P. Bàrberi, A. N. E. Birch, P. Boonekamp, S. Dachbrodt-Saaydeh, B. Graf, B. Hommel, J. E. Jensen, J. Kiss, P. Kudsk, et al. 2015. Eight principles of integrated pest management. Agron. Sustain. Dev. 35: 1199–1215.

Bebber, D. P., M. A. T. Ramotowski, and S. J. Gurr. 2013. Crop pests and pathogens move polewards in a warming world. Nat. Clim. Change 3: 985–988.

Bell, J. R., L. Alderson, D. Izera, T. Kruger, S. Parker, J. Pickup, C. R. Shortall, M. S. Taylor, P. Verrier, and R. Harrington. 2015. Long-term phenological trends, species accumulation rates, aphid traits and climate: five decades of change in migrating aphids. J. Anim. Ecol. 84: 21–34.

Birch, A. N. E., G. S. Begg, and G. R. Squire. 2011. How agro-ecological research helps to address food security issues under new IPM and pesticide reduction policies for global crop production systems. J. Exp. Biol. 62: 3251–3261.

Black, R., W. N. Adger, N. W. Arnell, S. Dercon, A. Geddes, and D. Thomas. 2011. The effect of environmental change on human migration. Global Environ. Change 21: S3–S11.

Bovet, A., and H. A. Makse. 2019. Influence of fake news in Twitter during the 2016 US presidential election. Nat. Commun. 10: 1–14.

Bowman, L. R., S. Donegan, and P. J. McCall. 2016. Is dengue vector control deficient in effectiveness or evidence? Systematic review and meta-analysis. PLoS Negl. Trop. Dis. 10: e0004551.

Caminade, C., K. M. McIntyre, and A. E. Jones. 2019. Impact of recent and future climate change on vector-borne diseases. Ann. N. Y. Acad. Sci. 1436: 157–173.

Campbell, B. L., H. Khachatryan, B. K. Behe, J. Dennis, and C. Hall. 2014. U.S. and Canadian consumer perception of local and organic terminology. IFAMR 17: 21–40.

Carlisle, L. 2016. Factors influencing farmer adoption of soil health practices in the United States: a narrative review. Agroecol. Sust. Food. 40: 583–613.

Carlisle, L., M. M. D. Wit, M. S. DeLonge, A. Iles, A. Calo, C. Getz, J. Ory, M. D. Katherine, R. Galt, B. Melone, et al. 2019. Transitioning to sustainable agriculture requires growing and sustaining an ecologically skilled workforce. Front. Sustain. Food Syst. 3: 1–8.

Chidawanyika, F., P. Mudavanhu, and C. Nyamukondiwa. 2019. Global climate change as a driver of bottom-up and top-down factors in agricultural landscapes and the fate of host-parasitoid interactions. Front. Ecol. Evol. 7: 1–13.

Choudhary, J. S., S. S. Mali, D. Mukherjee, A. Kumari, L. Moanaro, M. S. Rao, B. Das, A. K. Singh, and B. P. Bhatt. 2019. Spatio-temporal temperature variations in MarkSim multimodel data and their impact on voltinism of fruit fly, *Bactrocera* species on mango. Sci. Rep. 9: 1–12.

Clement, J. 2019. Most popular mobile social networking apps in the United States as of June 2019, by reach. (https://www.statista.com/statistics/579334/most-popular-us-social-networking-apps-ranked-by-reach/).

Cooper, J., and H. Dobson. 2007. The benefits of pesticides to mankind and the environment. Crop Prot. 26: 1337–1348.

Crutsinger, G. M., M. D. Collins, J. A. Fordyce, Z. Gompert, C. C. Nice, and N. J. Sanders. 2006. Plant genotypic diversity predicts community structure and governs an ecosystem process. Science 313: 966–968.

Cui, K., and S. P. Shoemaker. 2018. Public perception of genetically-modified (GM) food: a nationwide Chinese consumer study. Sci. Food 2: 1–8.

Deutsch, C. A., J. J. Tewksbury, M. Tigchelaar, D. S. Battisti, S. C. Merrill, R. B. Huey, and R. L. Naylor. 2018. Increase in crop losses to insect pests in a warming climate. Science 361: 916–919.

Donald, B. 2016. Stanford researchers find students have trouble judging the credibility of information online. (https://ed.stanford.edu/news/stanford-researchers-find-students-have-trouble-judging-credibility-information-online).

Ellsworth, P. C., A. Fournier, G. Frisvold, and S. E. Naranjo. 2017. Chronicling the socio-economic impact of integrating biocontrol, technology and knowledge over 25 years of IPM in Arizona, pp. 214. *In* Proceedings, 5th International Symposium on Biological Control of Arthropods, 11–15 September 2017. CABI, Wallingford, United Kingdom; Langkawi, Malaysia.

Estay, S. A., M. Lima, and F. A. Labra. 2009. Predicting insect pest status under climate change scenarios: combining experimental data and population dynamics modelling. J. Appl. Entomol. 133: 491–499.

Falt-Nardmann, J. J. J., K. Ruohomäki, O. P. Tikkanen, and S. Neuvonen. 2018. Cold hardiness of *Lymantria monacha* and *L. dispar* (Lepidoptera: Erebidae) eggs to extreme winter temperatures: implications for predicting climate change impacts. Ecol. Entomol. 43: 422–430.

FAO. **2009**. How to feed the world in 2050. *In* FAO (ed.), Synthesis report on the expert meeting on how to feed the world in 2050. Food and Agricultural Organization, Rome, Italy.

Farrar, J. J., M. E. Baur, and S. F. Elliott. 2016. Adoption of IPM practices in grape, tree fruit, and nut production in the western United States. J. Integr. Pest Manag. 7: 1–8.

Fernandes, M. E. S., F. M. Alves, R. C. Pereira, L. A. Aquino, F. L. Fernandes, and J. C. Zanuncio. 2016. Lethal and sublethal effects of seven insecticides on three beneficial insects in laboratory assays and field trials. Chemosphere 156: 45–55.

Foley, J. A., R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, et al. 2005. Global consequences of land use. Science 309: 570–574.

Foley, J. A., N. Ramankutty, K. A. Brauman, E. S. Cassidy, J. S. Gerber, M. Johnston, N. D. Mueller, C. O'Connell, D. K. Ray, P. C. West, et al. 2011. Solutions for a cultivated planet. Nature 478: 337–342.

Forrest, J. R. K. 2015. Plant–pollinator interactions and phenological change: what can we learn about climate impacts from experiments and observations? Oikos 124: 4–13.

Gabriel, D., S. M. Sait, W. E. Kunin, and T. G. Benton. 2013. Food production vs. biodiversity: comparing organic and conventional agriculture. J. Appl. Ecol. 50: 355–364.

Gage, K. L., T. R. Burkot, R. J. Eisen, and E. B. Hayes. 2008. Climate and vectorborne diseases. Am. J. Prev. Med. 35: 436–450.

Giles, K. L., and N. R. Walker. 2009. Dissemination and impact of IPM programs in US agriculture, pp. 481–505. *In* R. Peshin and A. K. Dawshan (eds.), Integrated pest management: dissemination and impact. Springer, Dordrecht.

Githeko, A. K., S. W. Lindsay, U. E. Confalonieri, and J. A. Patz. 2000. Climate change and vector-borne diseases: a regional analysis. Bull. World Health Organ. 78: 1136–1147.

Godfray, H. C. J., R. Beddington, I. R. Crute, L. Haddad, D. Lawrence, J. F. Muir, J. Pretty, S. Robinson, S. M. Thomas, and C. Toulmin. 2010. Food security: the challenge of feeding 9 billion people. Science 327: 812–818.

Gold, M. V. 1999. Sustainable agriculture: definitions and terms, pp. 1–40, United States Department of Agriculture Special Reference Briefs Series no. SRB 99-02. National Agricultural Library, Beltsville, MD.

Gray, M. E., S. T. Ratcliffe, and M. E. Rice. 2008. The IPM paradigm: concepts, strategies and tactics, pp. 1–13. *In* E. B. Radcliffe, W. D. Hutchinson, and R. E. Cancelado (eds.), Integrated pest management: concepts, tactics, strategies and case studies. Cambridge University Press, New York.

Green, R. E., S. J. Cornell, J. P. Scharlemann, and A. Balmford. 2005. Farming and the fate of wild nature. Science 307: 550–555.

Gu, S., P. Han, Z. Ye, L. E. Perkins, J. Li, H. Wang, M. P. Zalucki, and Z. Lu. 2018. Climate change favours a destructive agricultural pest in temperate regions: late spring cold matters. J. Pest Sci. 91: 1191–1198.

Hallman, W. K., A. O. Adelaja, B. J. Schilling, and J. T. Lang. 2002. Public perceptions of genetically modified foods: Americans know not what they eat. Rutgers, The State University of New Jersey, New Brunswick, NJ.

Hansen, J. W. 1996. Is agricultural sustainability a useful concept? Agric. Syst. 50: 117–143.

Harrington, R., I. Woiwod, and T. Sparks. 1999. Climate change and trophic interactions. Trends Ecol. Evol. 14: 146–150.

Harrington, R., R. A. Fleming, and I. P. Woiwod. 2001. Climate change impacts on insect management and conservation in temperate regions: can they be predicted? Agric. For. Entomol. 3: 233–240.

Haunschild, R., L. Leydesdorff, L. Bornmann, I. Hellsten, and W. Marx. 2019. Does the public discuss other topics on climate change than researchers? A comparison of explorative networks based on author keywords and hashtags. J. Informetr. 13: 695–707.

Higley, L. G., and W. K. Wintersteen. 1996. Thresholds and environmental quality, pp. 249–274. *In* L. G. Higley and L. G. Pedigo (eds.), Economic thresholds for integrated pest management. University of Nebraska Press, Lincoln, NE.

Hingston, S. T., and T. J. Noseworthy. 2018. Why consumers don't see the benefits of genetically modified foods, and what marketers can do about it. J. Mark. 82: 125–140.

Howard, P. 2005. What do people want to know about their food? Measuring central coast consumers' interest in food systems issues. CASFS 13: 1–4.

Howell, E. L., J. Nepper, D. Brossard, M. A. Xenos, and D. A. Scheufele. 2019. Engagement present and future: graduate student and faculty perceptions of social media and the role of the public in science engagement. PLoS One 14: e0216274.

Huang, Y. S., S. Higgs, and D. L. Vanlandingham. 2019. Emergence and re-emergence of mosquito-borne arboviruses. Curr. Opin. Virol. 34: 104–109.

Hughner, R. S., P. McDonagh, A. Prothero, C. J. S., II, and J. Stanton. 2007. Who are organic food consumers? A compilation and review of why people purchase organic food. J. Consum. Behav. 6: 94–110.

Hunter, M. C., R. G. Smith, M. E. Schipanski, L. W. Atwood, and D. A. Mortensen. 2017. Agriculture in 2050: recalibrating targets for sustainable intensification. BioScience 67: 386–391.

Hwong, Y., C. Oliver, M. Van Kranendonk, C. Sammut, and Y. Seroussi. 2017. What makes you tick? The psychology of social media engagement in space science communication. Comput. Human. Behav. 68: 480–492.

Isard, S. A., J. M. Russo, and E. D. DeWolf. 2006. The establishment of a national pest information platform for extension and education. Plant Health Progress. (http://www.plantmanagementnetwork.org/pub/php/review/2006/platform/).

Ju, R.-T., L. Gao, S.-J. Wei, and B. Li. 2017. Spring warming increases the abundance of an invasive specialist insect: links to phenology and life history. Sci. Rep. 7: 1–12.

Karp, D. S., R. Chaplin-Kramer, T. D. Meehan, E. A. Martin, F. DeClerck, H. Grab, C. Gratton, L. Hunt, A. E. Larsen, A. Martínez-Salinas, et al. 2018. Crop pests and predators exhibit inconsistent responses to surrounding landscape composition. Proc. Natl. Acad. Sci. USA 115: E7863–E7870.

Kershen, D. L. 2013. The contested vision for agriculture's future: sustainable intensive agriculture and agroecology. Creighton L. Rev. 46: 591–618.

Kistner, E. J. 2017. Climate change impacts on the potential distribution and abundance of the brown marmorated stink bug (Hemiptera: Pentatomidae) with special reference to North America and Europe. Environ. Entomol. 46: 1212–1224.

Kniss, A. R., S. D. Savage, and R. Jabbour. 2016. Correction: commercial crop yields reveal strengths and weaknesses for organic agriculture in the United States. PLoS One 11: e0165851.

Ko, H. 2016. In science communication, why does the idea of a public deficit always return? How do the shifting information flows in healthcare affect the deficit model of science communication? Public Understand. Sci. 25: 427–432.

Koleva, N. G., and U. A. Schneider. 2009. The impact of climate change on the external cost of pesticide applications in US agriculture. Int. J. Agric. Sustain. 7: 203–216.

Kremen, C., and A. Miles. 2012. Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. Ecol. Soc. 17: 40. doi:10.5751/ES-05035-170440.

Kremen, C., A. Iles, and C. Bacon. 2012. Diversified farming systems: an agroecological, systems-based alternative to modern industrial agriculture. Ecol. Soc. 17: 44. doi:10.5751/ES-05103-170444.

Lawson, A. E. 2009. Teaching inquiry science in middle and secondary schools. 1st ed. Sage, Los Angeles, CA.

Lazer, D. M. J., M. A. Baum, Y. Benkler, A. J. Berinsky, K. M. Greenhill, F. Menczer, M. J. Metzger, B. Nyhan, G. Pennycook, D. Rothschild, et al. 2018. The science of fake news. Science 359: 1094–1096.

Lefebvre, M., S. R. H. Langrell, and S. Gomez-y-Paloma. 2015. Incentives and policies for integrated pest management in Europe: a review. Agron. Sustain. Dev. 35: 27–45.

Leighton, P. A., J. K. Koffi, Y. Pelcat, L. R. Lindsay, and N. H. Ogden. 2012. Predicting the speed of tick invasion: an empirical model of range expansion for the Lyme disease vector *Ixodes scapularis* in Canada. J. Appl. Ecol. 49: 457–464.

Levine, E., J. L. Spencer, S. A. Isard, D. W. Onstad, and M. E. Gray. 2002. Adaptation of the western corn rootworm to crop rotation: evolution of a new strain in response to a management practice. Am. Entomol. 48: 94–107.

Liu, X. 2009. Beyond science literacy: science and the public. Int. J. Sci. Educ. 4: 301–311.

Lockeretz, W. 1988. Open questions in sustainable agriculture. Am. J. Altern. Agric. 3: 174–181.

Lockie, S., K. Lyons, G. Lawrence, and K. Mummery. 2002. Eating 'green': motivations behind organic food consumption in Australia. Sociol. Rural. 42: 23–40.

Losey, J. E., and M. Vaughan. 2006. The economic value of ecological services provided by insects. BioScience 56: 311–323.

Lounibos, L. P. 2002. Invasions by insect vectors of human disease. Annu. Rev. Entomol. 47: 233–266.

Magkos, F., F. Arvaniti, and A. Zampelas. 2003. Organic food: nutritious food or food for thought? A review of the evidence. Int. J. Food Sci. Nutr. 54: 357–371.

Maharjan, R., C. Jung, and L. Kafle. 2013. Feasibility of the trap cropping system for the management of hemipteran bugs on mungbean, *Vigna radiata* (L.) Wilczek in Nepal. Formosan Entomol. 33: 15–26.

Mahmud, J., J. Chen, and J. Nichols. 2014. Why are you more engaged? Predicting social engagement from word use. (https://arxiv.org/pdf/1402.6690).

Maino, J. L., P. A. Umina, and A. A. Hoffmann. 2017. Climate contributes to the evolution of pesticide resistance. Global Ecol. Biogeogr. 27: 223–232.

Marris, C. 2001. Public views on GMOs: deconstructing the myths. Stakeholders in the GMO debate often describe public opinion as irrational. But do they really understand the public? EMBO Rep. 2: 545–548.

Matzrafi, M. 2019. Climate change exacerbates pest damage through reduced pesticide efficacy. Pest Manag. Sci. 75: 9–13.

May, R. M., and R. J. H. Beverton. 1990. How many species? [and discussion]. Philos. Trans. Biol. Sci. 330: 293–304.

Medlock, J. M., K. M. Hansford, A. Bormane, M. Derdakova, A. Estrada-Peña, J. C. George, I. Golovljova, T. G. Jaenson, J. K. Jensen, P. M. Jensen, et al. 2013. Driving forces for changes in geographical distribution of *Ixodes ricinus* ticks in Europe. Parasit. Vectors 6: 1.

Metzger, M. J. 2007. Making sense of credibility on the web: models for evaluating online information and recommendations for future research. J. Am. Soc. Inf. Sci. Technol. 58: 2078–2091.

Miller, S. 2001. Public understanding of science at the crossroads. Public Understand. Sci. 10: 115–120.

Miller, H. I., and J. J. Cohrssen. 2018. Why can't food be genetically engineered and organic? Regulation 41: 4–6.

Moore, L. C., A. W. Leslie, C. R. R. Hooks, and G. P. Dively. 2019. Can plantings of partridge pea (*Chamaecrista fasciculata*) enhance beneficial arthropod communities in neighboring soybeans. Biol. Control 128: 6–16.

Mordecai, E. A., J. M. Cohen, M. V. Evans, P. Gudapati, L. R. Johnson, C. A. Lippi, K. Miazgowicz, C. C. Murdock, J. R. Rohr, S. J. Ryan, et al. 2017. Detecting the impact of temperature on transmission of Zika, dengue, and chikungunya using mechanistic models. PLoS Negl. Trop. Dis. 11: e0005568.

Munir, R. 2017. Science communication: effective use of social media for scientists. *In* Proceedings, 14th International Conference on Energy and Materials Research, 6–7 December 2017, Dallas, TX.

Neher, D. 1992. Ecological sustainability in agricultural systems: definition and measurement. J. Sustain. Agric. 2: 51–61.

Nickerson, R. S. 1998. Confirmation bias: a ubiquitous phenomenon in many guises. Rev. Gen. Psychol. 2: 175–220.

Oerke, E.-C. 2006. Crop losses to pests. J. Agric. Sci. 144: 31–43.

Oeschger, M. P., and C. E. Silva. 2007. Genetically modified organisms in the United States: implementation, concerns, and public perception. Adv. Biochem. Eng. Biotechnol. 107: 57–68.

Ogden, N. H., and L. R. Lindsay. 2016. Effects of climate and climate change on vectors and vector-borne diseases: ticks are different. Trends Parasitol. 32: 646–656.

Ogden, N. H., L. St-Onge, I. K. Barker, S. Brazeau, M. Bigras-Poulin, D. F. Charron, C. M. Francis, A. Heagy, L. R. Lindsay, A. Maarouf, et al. 2008. Risk maps for range expansion of the Lyme disease vector, *Ixodes scapularis*, in Canada now and with climate change. Int. J. Health Geogr. 7: 24.

Ogden, N. H., M. Radojevic, X. Wu, V. R. Duvvuri, P. A. Leighton, and J. Wu. 2014. Estimated effects of projected climate change on the basic reproductive number of the Lyme disease vector *Ixodes scapularis*. Environ. Health Perspect. 122: 631–638.

Osterrieder, A. 2013. The value and use of social media as communication tool in the plant sciences. Plant Methods 9: 1–6.

Paarlberg, R. L. 2001. Comparing and explaining developing-country policies towards GM crops, pp. 148–157. *In* R. L. Paarlberg (ed.), The politics of precaution: genetically modified crops in developing countries. International Food Policy Research Institute and The John Hopkins University Press, Baltimore, MD.

Pannell, D. J. 1999. Social and economic challenges in the development of complex farming systems. Agrofor. Syst. 45: 395–411.

Pedigo, L. P. 1989. Entomology and pest management. Macmillan Publishing Company, New York.

Peters, K., Y. Chen, A. M. Kaplan, B. Ognibeni and K. Pauwels. 2013. Social media metrics – a framework and guidelines for managing social media. J. Interact. Mark. 27: 281–298.

Peterson, R. K. D., L. G. Higley, and L. P. Pedigo. 2018. Whatever happened to IPM? Am. Entomol. 64: 146–150.

Phalan, B., A. Balmford, R. E. Green, and J. P. W. Scharlemann. 2011a. Minimising the harm to biodiversity of producing more food globally. Food Pol. 36: 62–62.

Phalan, B., M. Onial, A. Balmford, and R. E. Green. 2011b. Reconciling food production and biodiversity conservation: land sharing and land sparing compared. Science 333: 1289–1291.

Philips, C. M., M. A. Rogers, T. P. Kuhar. 2014. Understanding farmscapes and their potential for improving IPM programs. J. Integr. Pest Manag. 5: C1–C9.

Pilkay, G. L., F. P. Reay-Jones, M. D. Toews, J. K. Greene, and W. C. Bridges. 2015. Spatial and temporal dynamics of stink bugs in southeastern farmscapes. J. Insect Sci. 15: 23.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecol. Econ. 52: 273–288.

Pingali, P. L. 2012. Green revolution: impacts, limits, and the path ahead. Proc. Natl. Acad. Sci. USA 109: 12302–12308.

Ponisio, L. C., L. K. M'Gonigle, K. C. Mace, J. Palomino, P. D. Valpine, and C. Kremen. 2015. Diversification practices reduce organic to conventional yield gap. Proc. R. Soc. B 282: 1–15.

Power, A. G. 2010. Ecosystem services and agriculture: tradeoffs and synergies. Philos. Trans. R. Soc. Lond. B Biol. Sci. 365: 2959–2971.

Pretty, J. N., A. D. Noble, D. Bossio, J. Dixon, R. E. Hine, F. W. T. P. de Vries, and J. I. L. Morison. 2006. Resource-conserving agriculture increases yields in developing countries. Environ. Sci. Technol. 40: 1114–1119.

Ramankutty, N., A. T. Evan, C. Monfreda, and J. A. Foley. 2008. Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000. Global Biogeochem. Cy. 22: 1–19.

Ray, D. K., N. D. Mueller, P. C. West, and J. A. Foley. 2013. Yield trends are insufficient to double global crop production by 2050. PLoS One 8: e66428.

Rehman, A., L. Jingdong, R. Khatoon, and I. Hussain. 2016. Modern agricultural technology adoption its importance, role and usage for the improvement of agriculture. Am.-Eurasian J. Agric. Environ. Sci. 16: 284–288.

Ritchie, H., and M. Roser. 2013a. Crop yields. (https://ourworldindata.org/crop-yields).

Ritchie, H., and M. Roser. 2013b. Land use. (https://ourworldindata.org/land-use).

Roesch-McNally, G. E., A. D. Basche, J. G. Arbuckle, J. C. Tyndall, F. E. Miguez, T. Bowman, and R. Clay. 2018. The trouble with cover crops: farmers' experiences with overcoming barriers to adoption. Renew. Agric. Food Syst. 33: 322–333.

Roos, J., R. Hopkins, A. Kvarnheden, and C. Dixelius. 2011. The impact of global warming on plant diseases and insect vectors in Sweden. Eur. J. Plant Pathol. 129: 1–11.

Ryan, S. J., C. J. Carlson, E. A. Mordecai, and L. R. Johnson. 2019. Global expansion and redistribution of *Aedes*-borne virus transmission risk with climate change. PLoS Negl. Trop. Dis. 13: e0007213.

Saba, A., and F. Messina. 2003. Attitudes towards organic foods and risk/benefit perception associated with pesticides. Food Qual. Prefer. 14: 637–645.

Savage, S. 2014. An example of how much pesticides have changed. (https://biofortified.org/2014/01/an-example-of-how-much-pesticides-have-changed/).

Schoelitsz, B., B. G. Meerburg, and W. Takken. 2019. Influence of the public's perception, attitudes, and knowledge on the implementation of integrated pest management for household insect pests. Entomol. Exp. Appl. 167: 14–26.

Schrama, M., J. J. D. Haan, M. Kroonen, H. Verstegen, and W. H. V. D. Putten. 2018. Crop yield gap and stability in organic and conventional farming systems. Agric. Ecosyst. 256: 123–130.

Shearer, F. M., C. L. Moyes, D. M. Pigott, O. J. Brady, F. Marinho, A. Deshpande, J. Longbottom, A. J. Browne, M. U. G. Kraemer, K. M. O'Reilly, et al. 2017. Global yellow fever vaccination coverage from 1970 to 2016: an adjusted retrospective analysis. Lancet Infect. Dis. 17: 1209–1217.

Smith, A., and M. Anderson. 2018. Social media use 2018. (https://www.pewinternet.org/2018/03/01/social-media-use-in-2018/).

Smith, P. M., H. Bustamante, H. Ahammad, H. Clark, H. Dong, E. A. Elsiddig, H. Haberl, R. Harper, J. House, M. Jafari, et al. 2014. Agriculture, forestry and other land use (AFOLU), pp. 811–922. *In* O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, **et al.** (eds.), Climate change 2014, mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York.

Stern, V., R. Smith, R. van den Bosch, and K. Hagen. 1959. The integration of chemical and biological control of the spotted alfalfa aphid: the integrated control concept. Hilgardia 28: 81–101.

Stocklmayer, S., G. S. Aikenhead, J. Turney, L. J. Prelli, R. Eckersley, D. Sless, R. Shrensky, L. J. Rennie, J. K. Gilbert, P. Spinks, et al. 2001. Science communication in theory and practice. *In* S. M. Stocklmayer, R. Goré, and C. R. Bryant (eds.), 1st ed. Kluwer Academic Publishers and Springer, Amsterdam, The Netherlands.

Takeda, K., D. L. Musolin, and K. Fujisaki. 2010. Dissecting insect responses to climate warming: overwintering and post-diapause performance in the southern green stink bug, *Nezara viridula*, under simulated climate-change conditions. Physiol. Entomol. 35: 343–353.

Tal, A. 2018. Making conventional agriculture environmentally friendly: moving beyond the glorification of organic agriculture and the demonization of conventional agriculture. Sustainability 10: 1078.

Taylor, R. A. J., D. A. Herms, J. Cardina, and R. H. Moore. 2018. Climate change and pest management: unanticipated consequences of trophic dislocation. Agronomy 8: 7.

Tian, B., Z. Yu, Y. Pei, Z. Zhang, E. Siemann, S. Wan, and J. Ding. 2019. Elevated temperature reduces wheat grain yield by increasing pests and decreasing soil mutualists. Pest Manag. Sci. 75: 466–475.

Tilman, D., C. Balzer, J. Hill, and B. L. Befort. 2011. Global food demand and the sustainable intensification of agriculture. Proc. Natl. Acad. Sci. USA 108: 20260–20264.

Tito, R., H. L. Vasconcelos, and K. J. Feeley. 2018. Global climate change increases risk of crop yield losses and food insecurity in the tropical Andes. Global Change Biol. 24: e592–e602.

Tjaden, N. B., C. Caminade, C. Beierkuhnlein, and S. M. Thomas. 2018. Mosquito-borne diseases: advances in modelling climate-change impacts. Trends Parasitol. 34: 227–245.

Tobin, P. C., S. Nagarkatti, G. Loeb, and M. C. Saunders. 2008. Historical and projected interactions between climate change and insect voltinism in a multivoltine species. Global Change Biol. 14: 951–957.

Trewavas, A. 2001. Urban myths of organic farming. Nature 410: 409–410.

Trębicki, P., N. Nancarrow, E. Cole, N. A. Bosque-Pérez, F. E. Constable, A. J. Freeman, B. Rodoni, A. L. Yen, J. E. Luck, and G. J. Fitzgerald. 2015. Virus disease in wheat predicted to increase with a changing climate. Global Change Biol. 21: 3511–3519.

United Nations. 2010. The right to adequate food, pp. 49. *In* Human rights fact sheet. United Nation Office, Geneva, Switzerland. (https://www.ohchr.org/Documents/Publications/FactSheet34en.pdf).

United Nations. 2019. World population prospects 2019: highlights, pp. 2. New York. (https://population.un.org/wpp/Publications/Files/WPP2019_10KeyFindings.pdf).

U.S. Census Bureau. 2015. Millennials outnumber baby boomers and are far more diverse, Census Bureau reports. (https://www.census.gov/newsroom/press-releases/2015/cb15-113.html).

Van Lenteren, J. C. V. 2012. The state of commercial augmentative biological control: plenty of natural enemies, but a frustrating lack of uptake. BioControl 57: 1–20.

Vosoughi, S., D. Roy, and S. Aral. 2018. The spread of true and false news online. Science 359: 1146–1151.

Vraga, E. K., L. Bode, A.-B. Smithson, and S. V. Troller-Renfree. 2019. Accidentally attentive: comparing visual, close-ended, and open-ended measures of attention on social media. Comput. Human Behav. 99: 235–244.

Wacker, F. 2018. Food waste and food losses – importance of international partnerships and research. *In* Proceedings 12th International Working Conference on Stored Product Protection (IWCSPP), Julius-Kǜhn Institut, Berlin, Germany.

Walldorf, J. A., K. A. Date, N. Sreenivasan, J. B. Harris, and T. B. Hyde. 2017. Lessons learned from emergency response vaccination efforts for cholera, typhoid, yellow fever, and ebola. Emerg. Infect. Dis. 23. doi:10.3201/eid2313.170550.

Ward, N. L., and G. J. Masters. 2007. Linking climate change and species invasion: an illustration using insect herbivores. Global Change Biol. 13: 1605–1615.

Weaver, S. C., and W. K. Reisen. 2010. Present and future arboviral threats. Antiviral Res. 85: 328–345.

Wegner, L., and G. Zwart. 2011. Who will feed the world? The production challenge, pp. 66. Oxfam Research Reports, Cowley, Oxford, United Kingdom. (https://www-cdn.oxfam.org/s3fs-public/file_attachments/who-will-feed-the-world-rr-260411-en_4.pdf).

Wezel, A., M. Casagrande, F. Celette, J.-F. Vian, A. Ferrer, and J. Peigné. 2014. Agroecological practices for sustainable agriculture. A review. Agron. Sustain. Dev. 34: 1–20.

WHO. 2013. International code of conduct on the distribution and use of pesticides: guidelines on data requirement for the registration of pesticides, pp. 74. Viale delle Terme di Caracalla, Rome, Italy.

Wilen, C. A., V. F. Lazaneo, and S. Parker. 2011. Does the general public relate to the term 'integrated pest management?' JOE 49. https://www.joe.org/joe/2011february/rb3.php.

Williamson, C. S. 2007. Is organic food better for our health. Nutr. Bull. 32: 104–108.

Wilson, H., and K. Daane. 2017. Review of ecologically-based pest management in California vineyards. Insects 8: 108. doi:10.3390/insects8040108.

Yamamura, K., and K. Kiritani. 1998. A simple method to estimate the potential increase in the number of generations under global warming in temperate zones. Appl. Entomol. Zool. 33: 289–298.

Yap, A., L. G. Snyder, and S. Drye. 2018. The information war in the digital society: a conceptual framework for a comprehensive solution to fake news. ASSJ 3: 1214–1221.

Ziter, C., E. A. Robinson, and J. A. Newman. 2012. Climate change and voltinism in Californian insect pest species: sensitivity to location, scenario and climate model choice. Global Change Biol. 18: 2771–2780.