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PLANT SCIENCE SCAN

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BACKGROUND: The Plant Health Science Division of the Canadian Food Inspection Agency routinely scans external sources to identify information that might be of possible regulatory significance or interest to Canada's national plant health. This Plant Science Scan report was prepared by the Canadian Food Inspection Agency's staff as a mechanism to highlight potential items of interest, raise awareness and share significant new information related to plant health.

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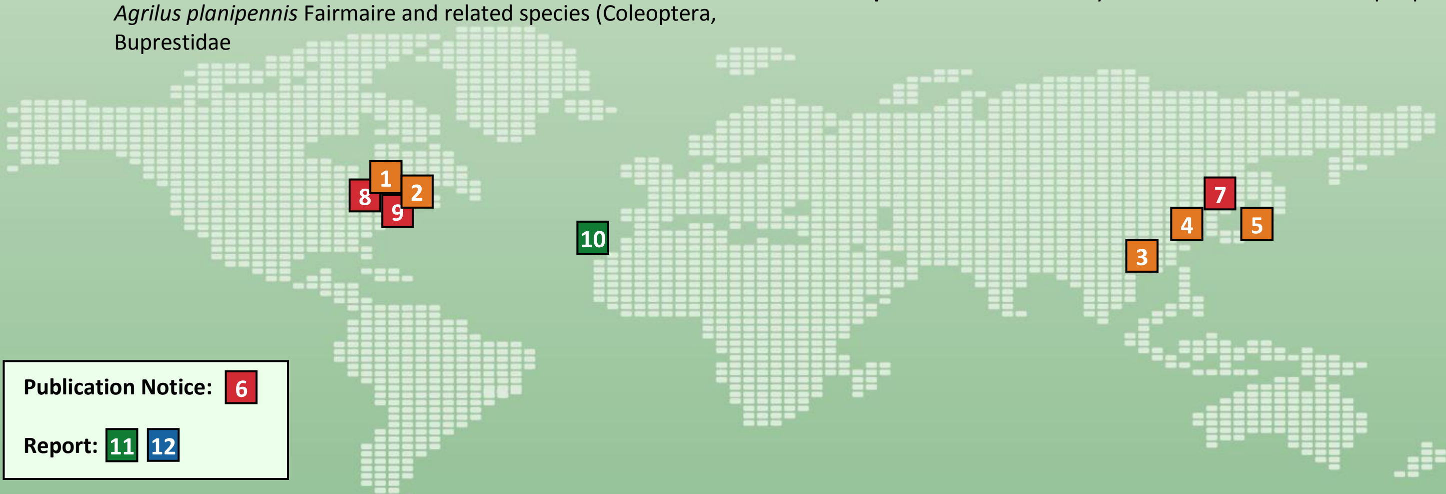

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Pathology

1 Update: Mechanisms of resistance to Dutch elm disease in American elm

Since its introduction from Europe, in the 1930s, Dutch elm disease (DED) has decimated American elm (*Ulmus americana*) trees across North America. The disease is caused by at least two fungal species; *Ophiotstoma ulmi* and, the more aggressive, *O. novo-ulmi* which has established throughout the native range of American elms in Canada (Nova Scotia to Saskatchewan). Although tolerant elm cultivars have been identified and released, the mechanisms driving tolerance to DED have not been well understood and true resistance has not yet been achieved. Identifying the specific mechanisms would be the first step towards cellular breeding of resistant cultivars.

A recent study led by researchers at the University of Guelph provided novel insight into the molecular mechanisms involved in DED resistance by investigating the differential regulation of disease-responsive genes in tolerant and susceptible genotypes of American elm. Using a modified CTAB method for RNA extraction from the woody tissues of elm stems, the researchers found that molecular events within the first four days after infection are critical and occur differently in resistant and susceptible trees. Tolerance to DED was best characterized as a simultaneous induction of defence-related genes and jasmonic acid (JA) at 96 hours post inoculation (hpi). Genes encoding pathogenesis-related proteins (i.e *PR4*, *PR5b*), proteinase inhibitors, pseudo-hevein and E-class P450 showed ≥ 2-fold higher expression in the tolerant 'Valley Forge' than the susceptible clone. Most of the genes also showed upregulation in the susceptible genotype at some point post-inoculation, suggesting that differences between tolerance and sensitivity to DED are not necessarily based on the presence or absence of certain disease-responsive genes, but rather by timing and level of gene expression. Analysis of the levels of endogenous plant defense molecules, including JA and salicylic acid (SA) in tolerant and susceptible saplings suggested that the exogenous application of SA and methyl-jasmonate could be performed to induce the expression of disease-responsive genes, which was further confirmed by field observations.

Previous research on DED has centered on the role of a phytotoxic protein, cerato ulmin (CU). Molecular investigations during the current study also looked at the expression of CU as an example of how endogenous plant defense hormones can alter the expression of fungal genes. The results indicated that the expression of CU was moderated by endogenous SA and JA and that this response was unique among aggressive and non-aggressive fungal strains. Moreover, the non-aggressive strain was more affected by SA, pointing to the possibility of selection pressure motivated by tolerance to SA.

Together, the findings of the current study not only provide documentation of molecular differences between DED-tolerant and sensitive American elm genotypes, but also a verified template for monitoring transcriptomic changes during *Ulmus-Ophiostoma* interactions and novel insights into fungal responses of plant defense hormones.

SOURCE: Sherif, S.M. Shukla, M.R., Murch, S.J., Bernier, L. and Saxena, P.K. (2016) Simultaneous induction of jasmonic acid and disease-responsive genes signifies tolerance of American elm to Dutch elm disease. Scientific Reports 6: 21934 DOI: 10.1038/srep21934

2 Update: First report of *Botryosphaeria corticola* (bot canker of oak) in Maine

Botryosphaeria corticola (anamorph *Diplodia corticola*) was detected in Maine (United States) in August 2014 (Aćimović et al. 2015). Dead and partially wilted red oaks (*Quercus rubra*) were observed along the Saco River near the city of Biddeford. This pathogen has previously been reported from several countries in Europe (France, Greece, Hungary, Italy, Portugal and Spain), Africa (Morocco and Tunisia) and more recently in the United States (California, Florida and Texas) (Dreaden et al. 2011; Luque et al. 2008; Lynch et al. 2010; Úrbez-Torres et al. 2009). This new report represents an important increase in distribution and, to our knowledge, a first report of this pathogen on red oak.

This pathogen causes the degradation of vascular tissue which leads to tip dieback and branch canker in several *Quercus* spp., as well as canker and dieback symptoms in grapevine (*Vitis vinifera*) (Aćimović et al. 2015; Dreaden et al. 2011). It has mostly been known as a pest of cork oak (*Quercus suber*) in Europe. *Botryosphaeria* fungi are typically opportunistic pathogens that live as endophytes within plants, but can become pathogenic when the plant is stressed. Environmental stress factors such as drought, heat and freezing are believed to increase the susceptibility of oak to this disease (Dreistadt 2013).

Botryosphaeria corticola is currently not a quarantine pest to Canada.

SOURCES: Aćimović, S. G., Harmon, C. L., Bec, S., Wyka, S., Broders, K. and Doccola, J. J. (2015) First report of *Diplodia corticola* causing decline of red oak (*Quercus rubra*) trees in Maine. Plant Disease 100(3): 649.

Dreaden, T. J., Shin, K. and Smith, J. A. (2011) First report of *Diplodia corticola* causing branch cankers on live oak (*Quercus virginiana*) in Florida. Plant Disease 95(8): 1027-1027.

Dreistadt, S. H. (2013) Forest and right of way pest control, 2nd Edition. UCANR Publications.

Luque, J., Pera, J. and Parladé, J. (2008) Evaluation of fungicides for the control of *Botryosphaeria corticola* on cork oak in Catalonia (NE Spain). Forest Pathology 38(3): 147-155.

Lynch, S. C., Eskalen, A., Zambino, P. and Scott, T. (2010) First report of bot canker caused by *Diplodia corticola* on coast live oak (*Quercus agrifolia*) in California. Plant Disease 94(12): 1510-1510.

Úrbez-Torres, J. R., Adams, P., Kamas, J. and Gubler, W. D. (2009) Identification, incidence, and pathogenicity of fungal species associated with grapevine dieback in Texas. American Journal of Enology and Viticulture 60(4): 497-507.

3 New Host: *Pseudomonas syringae* pv. *actinidiae* isolated from non-kiwifruit plant species in China

Kiwifruit bacterial canker (KBC), caused by *Pseudomonas syringae* pv. *actinidiae* (Psa), is a destructive plant pathogen that can seriously affect orchards of *Actinidia* species, including *A. deliciosa* and *A. chinensis,* two species that constitute the majority of kiwifruit grown commercially around the world. It was first described in Japan in the early 1980's and since 2008, a highly aggressive strain, characterized as biovar 3, has spread throughout the main producing countries in Europe (France, Germany, Italy, Portugal, Slovenia, Spain, Switzerland and Turkey), East Asia (China, Japan and South Korea), Oceania (Australia and New Zealand) and Chile. Since its discovery, Psa has only been known to infect *Actinidia* species, while little remained known about its potential to colonize alternate hosts. However, during field surveys in the summer of 2012, 2013 and 2014, suspicious foliar spots were observed on three non-kiwifruit plants growing under or nearby kiwifruit plants infected by Psa in Anhui Province, China. A recent study by Liu et al. (2016) investigated whether the symptoms could be related to Psa and found that all 11 bacterial isolates tested were Psa biovar 3.

The findings were based on results from two end-point PCR assays, sequence analysis of two effector genes and multilocus sequence typing (MLST) of five housekeeping genes. The three wild plant species from which the pathogen was recovered include: *Alternanthera philoxeroides, Paulownia tomentosa* and *Setaria viridis.*

Evidence that Psa can migrate to non-kiwifuit plant raises new issues about the means by which the disease can spread at local and international scales and may have implications on the measures taken to prevent and control the spread of the disease. Symptoms of KBC include cankers with rusty or white exudates on vines and branches, brown spots surrounded by chlorotic haloes on leaves, blight of new shoots and wilted sepals and blasted petals on flowers. It is not known to occur in Canada and is considered a pathogen of quarantine concern due to its potential to establish and cause direct damage through losses of yield and stock material.

SOURCE: Liu, P., Xue, S., He, R. Hu, J., Wang, X., Jia, B., Gallipoli, L. Mazzaglia, A., Balestra, M. and Zhu, L. (2016) *Pseudomonas syringae* pv. *Actinidiae* isolated from non-kiwifruit plant species in China. European Journal of Plant Pathology: 1-12. DOI 10.1007/s10658-016-0863-4

4 New Disease: Zonate leaf spot caused by *Hinomyces pruni* on *Prunus mandshurica*

The first report of a new disease on *Prunus mandshurica* (Manchurian apricot) has been reported in Korea. *Hinomyces pruni* was determined to be the cause of zonate leaf spot. Symptoms included the development of greyish green to brownish grey leaf spots with no border lines that eventually coalesced, resulting in leaf blight and defoliation (Cho et al. 2015). This disease has also been recorded to cause zonate leaf spot on several *Prunus* species in Japan, including *P. mume* (Chinese plum), *P. armeniaca* (apricot), *P. persica* var. *vulgaris* (peach), and *P. salicina* (plum) (Cho et al. 2015).

Prunus mandshurica is native to northeast China and Korea, and is a cold-adapted species. It has been used in breeding projects to increase frost tolerance in apricot (Cho et al. 2015).

SOURCE: Cho, S.E., Park, J.H., Lee, S.H., Lee, C.K., and Shin, H.D. (2015) Zonate leaf spot of *Prunus mandshurica* caused by *Hinomyces pruni* in Korea. Journal of Phytopathology 163: 1019-1022.

5 New Disease: A new rust pathogen of willow, *Melampsora salicis-bakko*, in Japan

Several rust fungi have been associated with willow in Europe and Asia, many of which have not been reported from North America. These rust fungi cause damage in natural environments and also in willow biofuel plantations. The fungus *Melampsora caprearum* is widely reported across Europe and parts of Asia (Farr and Rossman 2016), but not from North America. A newly described species, *Melampsora salicis-bakko*, resembles *M. caprearum* in morphology and symptoms (Zhao et al. 2016), and therefore may have previously been misdiagnosed in Japan as the more common *M. caprearum*.

The new species was found on *Salix bakko*, *S. hultenii* and *S. leucopithecia,* willow species native to Japan and East Asia, which are of interest in biofuel production. It is not currently known whether this species can infect other *Salix* species.

The importation of willow into Canada is banned from areas outside of the United States.

SOURCES: Farr, D.F. and Rossman, A.Y. (2016) Fungal Databases, Systematic Mycology and Microbiology Laboratory, ARS, USDA. Retrieved June 2, 2016, from http://nt.ars-grin.gov/fungaldatabases/

Zhao, P., Wang, Q.H., Tian, C.M., Wang, Q. and Kakishima, M. (2016) *Melampsora salicis-bakko*, a new species on willows in Japan evidenced by morphological and molecular phylogenetic analyses.

Mycological Progress 15 (32): 10.1007/s11557-016-1175-y

Entomology

6 Publication Notice: Illustrated guide to the Emerald Ash Borer *Agrilus planipennis* Fairmaire and related species (Coleoptera, Buprestidae)

An open access guide has been published as an aid for the identification of the invasive buprestid *Agrilus planipennis* Fairmaire, commonly known as the Emerald Ash Borer (EAB), and related species. Many of the most recent and devastating invasive forest insect pests in North America have come from Asia, including EAB. The guide not only provides a solid grouping of EAB's closest relatives, but also the means to distinguish EAB from other potential invasive Asian *Agrilus* in order to quickly and accurately identify potential threats to North American forest resources.

Open access:
http://www.fs.fed.us/nrs/pubs/jrnl/2015/nrs_2015_chamorro_001.pdf

SOURCE: Chamorro, M. L, Jendek, E., Haack, R. A., Petrice, T.R., Woodley, N.E., Konstantinov, A.S., Volkovitsh, M. G., Yang, X.-K., Grebennikov, V.V. and Lingafelter, S. W. (2015) Illustrated Guide to the Emerald Ash *Borer Agrilus planipennis* Fairmaire and Related Species (Coleoptera, Buprestidae). Pensoft Publishers, Sofia-Moscow, Bulgaria, 197 pp.

7 Surveillance: Detection of Scolytinae beetles using host volatile and Cerambycidae pheromone lure combinations

For more than a decade, traps baited with host volatiles and/or bark beetle pheromones have been used for surveillance of exotic bark and wood-boring beetles in North America. This method has been reasonably successful at detecting bark and ambrosia beetles (Coleoptera: Curculionidae: Scolytinae), but less so for species of longhorn beetles (Coleoptera: Cerambycidae). Recent discoveries of long-distance sex and aggregation pheromones of Cerambycidae have led to the use of racemic blends as well as pure enantiomers in traps, significantly increasing the detection rate of several species of cerambycids. Although the combination of pheromones and host volatiles on the same trap has synergized attraction of Scolytinae and Cerambycidae individually, relatively little is known about the effects of combining longhorn beetle pheromones and host volatiles on the detection of Scolytinae.

A recent study by Sweeney et al. (2016) investigated these effects by testing the relative efficacy of various combinations of host volatile and longhorn beetle pheromone lures for the surveillance and detection of Scolytinae in the Russian Far East. Five lure combinations were tested and more than 12, 000 specimens from 36 species of Scolytinae were collected in two field trapping bioassays. The lure combinations of spruce blend (racemic α-pinene, (–) β-pinene, (+)-3-carene, (+)-limonene, and α-terpinolene) and ethanol captured significant numbers of four bark beetles that infest conifers: *Hylastes brunneus, H. obscurus, Ips typographus,* and *Dryocoetes stratius* compared with unbaited traps. The addition of the longhorn beetle pheromones, *E*-fuscumol or *E*-fuscumol acetae to traps baited with spruce blend and ethanol slightly reduced mean catches of *D. striatus,* but otherwise did not affect catch of any Scolytinae species. By themselves, the longhorn beetle pheromones, racemic hydroxyhexan-2-one and racemic hydroxyoctan-2-one, were not attractive to any Scolytine species; however, when added to ethanol-baited traps, hydroxyhexan-2-one lures significantly increased mean catch of *S. tycon*, hydroxyoctan-2-one lures significantly reduced mean catches of *A. maiche* and *X. attenuatus*, and lures of either hydroxyketone significantly reduced mean catch of *T. lineatum*. The lure treatments that detected the greatest number of species were spruce blend plus ethanol and hydroxyhexan-2-one plus ethanol.

Despite the efficacy demonstrated by traps baited with ethanol and spruce blends for particular species of Scolytinae, approximately half of the species known to be present at the site were not detected. Overall, the results suggest that combining hydroxyhexan-2-one and fuscumol on a single trap can increase the number of species of Scolytinae and Cerambycidae, reducing survey costs without significantly reducing detection efficacy, however, some multiple lure combinations reduce the attraction of certain species. Knowledge of how different target species respond to different lure combinations must therefore be taken into consideration when designing operational surveys.

SOURCES: Sweeney, J.D., Silk, P., Grebennikov, V. and Mandelshtam, M. (2016) Efficacy of semiochemical-baited traps for detection of Scolytinae species (Coleoptera: Curculionidae) in the Russian Far East. European Journal of Entomology 113: 84-97 DOI: 10.14411/eje.2016.010

8 New Pest: Invasive earthworms can be a threat to the growth of North American trees

Many gardeners, horticulturalists and soil scientists, regard earthworms as good for the soil, the garden and the environment as they help increase the amount of air and water that gets into the soil, break down organic matter into things that plants can use and leave behind castings that are a very valuable type of fertilizer. Thus, earthworms are not usually associated with any negative attributes. But amidst all the positive attributes of encouraging worm-enriched gardening practices, there has been an earthworm concern emerging in the forestry world.

Earthworms are now been recognized as potential significant agents of mortality for seeds of forest tree species. Though reported by Charles Darwin as long ago as 1881, this aspect of invasive earthworm ecology has largely been overlooked. A recent study by Cassin and Kotanen (2016) provides evidence that seeds entering the soil seedbank in temperate forests are vulnerable to granivory by invasive earthworms. Overall, it was found that 73 % of seeds of 6 ecologically important forest species were removed from the soil surface over 2 weeks in a *Lumbricus terrestris* microcosm experiment; 30 % vanished entirely, and presumably were destroyed. These species are *Betula alleghaniensis*, *Larix laricina*, *Lonicera canadensis*, *Maianthemum racemosum*, *Pinus banksiana*, and *Tsuga canadensis*.

The authors opined that though the negative impacts of earthworms on some tree seeds may be masked by the stronger effects of small rodents like grey squirrels and eastern chipmunks, earthworms are still capable of selectively removing seeds with certain traits, and in particular the small-seeded species typically less preferred by the rodents.

It is well known that the native earthworms in the northern part of US and Canada were eradicated by glaciers during the last ice age, so this region of the world has probably been earthworm free for tens of thousands of years. Thus, every earthworm currently found in this part of the world is in fact an invader, probably from Europe.

Millions of earthworms are produced or imported into Canada annually for composting or for use as fish bait. The general perception is that earthworms are beneficial organisms. This study adds to the growing body of evidence on the negative impact of earthworms.

SOURCES: Cassin, M. C. and Kotanen, P. M. (2016) Invasive earthworms as seed predators of temperate forest plants. *Biological Invasions*. DOI 10.1007/s10530-016-1101-x. Published, March 29, 2016.

9 Biocontrol: Host-specific parasitic wasp, *Spathius galinae*, approved for release in the United States to control the emerald ash borer

Since its initial detection in southeast Michigan in 2002, the emerald ash borer (EAB), *Agrilus planipennis,* has spread rapidly throughout the Midwest and eastern United States, and into southeastern Canada where it is found in Ontario and southwestern Quebec. Although several native parasitoids in North America attack EAB, their prevalence is relatively low compared to that of parasitoids in northeast Asia where the buprestid originated. In 2007, a biological control program was initiated in the United States that focused on the introduction of three natural enemy parasitoids from EAB's indigenous range in China, including *Tetrastichus planipennisi, Oobius agrili* and *Spathius agrili*. All three have been recovered following release; however, only *T. planipennisi* and *O. agrili* have been recovered consistently more than one year after release (USDA, 2015). Although these species are establishing and dispersing, both have limitations that affect their ability to successfully control EAB populations. *Oobius agrili* is a very small insect, dispersing much slower than *T. planipennisi,* and is also solitary with only one adult emerging from an EAB egg. *Tetrastichus planipennisi* is a gregarious parasitoid, producing 57 adults per EAB larva; however, it is a relatively small insect with a short ovipositor that cannot parasitize EAB larvae under the thick bark of larger trees (USDA, 2015).

To complement biological control efforts, *Spathius galinae* (Hymenoptera: Braconidae), a specialist parasitoid of EAB larvae that was described in 2009 from the Russian Far East (Belokobylskij et al., 2012), is being released for the first time in borer-infested regions of the United States (USDA 2015). *Spathius galinae* is gregarious, with typically 2-15 progeny developing on a host (USDA, 2015). Compared to *T. planipennisi, S. galinae* has an ovipositor that is up to twice as long, allowing it to attack hosts in large, reproductive-age trees (Abell et al., 2012). Climate matching indicates that this species is also well-suited for introduction in northern regions where the Chinese congener, *S. agrili,* has had little success (Hooie et al., 2015).

The approval for the release of *S. galinae* results from research at the University of Delaware and the USDA's Agricultural Research Service (ARS) which provided information necessary for regulatory agencies to conduct a risk assessment (USDA 2015). One study, by Duan et al. (2015), examined host specificity and found that *S. galinae* did not attack bark beetles (*Hylesinus* spp.) or longhorned beetles (Cerambycidae) that coexisted with EAB on infested ash trees in the Russian Far East, nor did it attack 14 out of 15 non-target wood-boring insects tested in ash and non-ash trees during quarantine laboratory studies. Together, the results indicate that the host specificity of *S. galinae* is restricted within the host genus *Agrilus*. A more recent article by Watt et al. (2016) looked at temperature on development and found that 25°C was the optimal temperature for mass-rearing, while at 35°C the eggs desiccated and did not hatch. The study determined that *S. galinae* can be effective in attacking EAB larvae in the early spring or later fall when the ambient temperature is around 15°C. An effective rearing program has been developed as a result and the parasitoid colony has been transferred to the USDA-APHIS rearing facility in Brighton, Michigan where tens of thousands of these parasitoids will be produced and sent to northeastern states for release (Thomas, 2016).

SOURCES: Abell, K.J., Duan, J.J, Bauer, L. Lelito, J.P. and van Dreisch R.G. (2012) The effect of bark thickness on host partitioning between *Terastichus plannipennisi* (Hymen: Uolohphida) and *Atanycolus* spp. (Hymen: Braconidae), two parasitoids of emerald ash borer (Coleop: Buprestidae). Biological Control 63: 320-325.

Belokobylskij, S.A., Yurchenko, G.I. Strazanac, J.S., Zaldívar-Riveró, N.A. and Mastro, V. (2012) A new emerald ash borer (Coleoptera: Buprestidae) parasitoid species of *Spathius* Nees (Hymenoptera: Braconidae: Doryctinae) from the Russian Far East and South Korea. Annals of the Entomological Society of America 105: 166-178.

Hooie, N.A., Wiggins G.J., Lambdin, P.L., Grant, J.F., Powell, S.D. and Lelito, J.P. (2015) Native parasitoids and recovery of *Spathius agrili* from the areas of release against emerald ash borer in eastern Tennessee, USA. Biocontrol Science and Technology 25(3): 345-351.

Thomas, A. 2016. UD, USDA researchers study natural enemies of tree-killing emerald ash borer. University of Delaware College of Agriculture and Natural Resources. Available online: http://canr.udel.edu/blog/ud-usda-researchers-study-natural-enemies-of-tree-killing-emerald-ash-borer/ [Accessed June 2016].

USDA (2015) Field Release of the Parasitoid *Spathius galinae* for the Biological Control of the Emerald Ash Borer (*Agrilus planipennis*) in the Contiguous United States. Environmental Assessment, pp. 1-33.

Watt, T.J., Duan, J.J., Tallamy, D.W., Hough-Goldstein, J., Ilvento, T.W., Yue, X. and Ren, H. (2016) Reproductive and developmental biology of the emerald ash borer parasitoid *Spathius galinae* (Hymenoptera: Braconidae) as affected by temperature. Biological Control 96: 1-7.

Botany

10 Spread: Raptors as secondary dispersers of weed seeds

Birds are well known as primary dispersal agents for seeds, but their role as secondary dispersers is less well understood. Secondary seed dispersal, and specifically diplochory, is seed dispersal that occurs in a sequence of two or more distinct events, each one involving a different dispersal agent. Secondary seed dispersal often occurs over long distances, as the home-ranges of secondary dispersers may be greater than those of primary dispersers, and the complex ecological processes involved can be crucial for colonization, range expansion, and distribution of genetic variation in plant populations.

In a recently published study, two native predatory raptors in the Canary Islands, the common buzzard (*Buteo buteo*) and the European kestrel (*Falco tinnunculus*), were shown to be important secondary dispersers of seeds after feeding on two invasive alien mammals, European rabbits (*Oryctolagus cuniculus*) and Barbary ground squirrels (*Atlantoxerus getulus*), which carried the seeds in their guts. A total of 300 and 319 pellets were examined from the two bird species, respectively, and contained seeds of 39 and 62 different plant species intermingled with the remains of prey, with a total of over 11,000 individual seeds observed. All were considered weeds except for three fleshy-fruited plants, although it is unclear how the authors defined 'weeds' in this context. Four and seven of the species occurred with a frequency of greater than 10% in the pellets of the two raptors, respectively. These species were then used for a germination experiment, and despite a time interval between pellet collection and planting, almost 10% of seeds germinated, even after passing through two digestive processes, one inside the mammal and the other inside the raptor.

This study suggests that raptors are more important as secondary seed dispersers than previously thought, particularly when small herbivorous mammals are the main prey. It also highlights the complex interactions that can occur between native and invasive species where their ranges overlap, and widens the scope of potential ecological consequences of raptor involvement in seed dispersal. The large size and mobility of raptors such as the common buzzard suggest the possibility of long distance seed dispersal on a wider geographical scale. Understanding processes such as these could be important in the study of the establishment and spread of invasive plant populations in new areas.

SOURCE: López-Darias, M. and Nogales, M. (2016) Raptors as legitimate secondary dispersers of weed seeds. Ibis 158(2): 428-432.

11 Report: State of the World's Plants

Researchers from the Royal Botanic Gardens, Kew (RBC Kew) and numerous partners have produced the first-ever report on the status of knowledge of the world's plants. This ambitious report focuses on three themes: what we know and don't know about plants, global threats to plants, and international policies and agreements in place to protect plants. It is the first outcome of what will become an annual process to add to the knowledge base on the world's plants, with the aim of raising the profile of plants around the world and identifying where additional research and policy focus is required.

The report provides many useful facts on plants and threats to plants. The authors estimate that there are 391,000 vascular plant species currently known to science, with over 2,000 new species being added per year in recent years. Worldwide, plants are facing major threats from climate change, land-cover change, invasive species and plant diseases, to the extent that an estimated 21% of species are now threatened with extinction. Climate change results in three possible outcomes for plant species: extinction, migration (i.e., permanent range shifts), or *in situ* adaptation. Over 10% of the world's vegetated area is considered highly sensitive to climate variability and is particularly at risk. Secondly, land-cover change is rampant. All but one of the world's 14 biomes have experienced over 10% land cover change in just the past decade, and the majority of those biomes exhibit decreased productivity. Thirdly, invasive species are a major driver of biodiversity loss, and their economic costs have been estimated at nearly 5% of the world economy. To date, a total of 4,979 plant species (1.3% of all plants) have been documented as invasive outside their natural range, where they impact native plant communities. Plant diseases are also a key threat to plant health, and there are significant areas of the world that are vulnerable but lacking in research. The RBG Kew Report identifies *The Convention on International Trade in Endangered Species of Wild Fauna and Flora* (CITES) and the *Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization* (ABS) to the Convention on Biological Diversity as two international agreements in place to deal with some of the threats to the world's plants.

Some interesting parallels can be made between this report and a 2008 CFIA report which focused specifically on invasive alien plants in Canada. The CFIA report focused on three similar themes, namely what we know about invasive alien plants in Canada, impacts of invasive plants, and Canada's response to invasive alien plants. Both reports are extremely useful because they provide a baseline on the status of plants and/or invasive plants at international and national levels, respectively. In future years, these baselines will prove vital for assessing the effectiveness of current policies and programs for addressing threats to plants.

SOURCES: Canadian Food Inspection Agency (2008) Invasive Alien Plants in Canada. CFIA, Ottawa, Ontario.

Royal Botanic Gardens, Kew (2016) The State of the World's Plants Report – 2016. RBG Kew, London, England.

Biotechnology

12 Report: National Academy of Sciences releases GE crop report

The U.S. National Academy of Sciences (NAS) released a consensus report this May titled *Genetically Engineered [GE] Crops: Experiences and Prospects*. The report intends to provide an independent, objective examination of the economic, agronomic, health, safety and other effects of GE crops and food. The report considers emerging technologies (i.e. genome editing, synthetic biology) and makes recommendations for research, regulation, and risk assessment of GE crops. Canada's regulatory system is used as an illustrative example.

Report authors did not find substantiated evidence that GE crops altered the risk to human health when compared to conventional crops, nor did they find a conclusive causal relationship between GE crops and any environmental problem. Overall, GE crops were economically favorable for growers in the early years of adoption. Realizing widespread benefits of GE crops in the future will depend on institutional support and access to profitable local and global markets, especially for growers in developing countries.

Emerging technologies

Emerging technologies are making it difficult to differentiate between crops modified using genetic engineering and conventional breeding. For example, CRISPR/Cas9, a new gene editing technique, may precisely change the plant genome without introducing foreign DNA. In crops, CRISPR/Cas9 may be used to improve tolerance to drought and temperature, increase photosynthetic efficiency and nitrogen use, and enhance nutrient content. Insect and disease resistance targeting more pests are likely to be introduced into more crops. These traits will likely increase harvestable yields and decrease crop losses to major insect or disease outbreaks. It remains to be seen if complex genetic changes improving photosynthesis, nutrient-use efficiency, and maximum yield will be successfully developed and commercialized.
In the future, "-omics" techniques, for example DNA ("genomics"), proteins ("proteomics") and metabolites ("metabolomics"), that can compare the DNA sequence, RNA expression, and molecular composition of a new variety with a comparator in widespread use, may allow testing for novel characteristics. Research is needed to correlate -omic patterns to specific traits and ultimately to potential risk. More research is also needed to understand the range of variation at the systems level (DNA, RNA, protein, and metabolites) in both conventionally bred and GE crops.

Implications for regulation

Both genetic engineering and conventional breeding can alter crops and foods resulting in safety issues. Because of this, the report recommends that the product itself should be regulated and not the process by which it was created (i.e., genetic engineering or conventional breeding techniques). The safety of new plant varieties should be assessed if they have intended or unintended novel characteristics with potential hazards.

In the U.S., the Animal and Plant Health Inspection Service (APHIS) and the Environmental Protection Agency (EPA) determine which plants to regulate at least partially on the process by which they are developed. The process-based approach is becoming less defensible as emerging technologies blur the distinctions between genetic engineering and conventional breeding. The report recommends safety testing for new plant varieties with intended or unintended novel characteristics with potential hazards, regardless if they were introduced using genetic engineering or conventional breeding. This is consistent with Canada's current regulatory system where any plant with a novel trait is regulated. APHIS has proposed a new trigger for its regulatory authority and revised definitions to allow for regulation of a wider range of products, including those derived using new plant breeding techniques. Proposed changes would be more consistent with Canada's regulatory system and the recommendations of this report.

Because emerging technologies may cause both incremental changes without substantial risk and major changes with increased risk, the report recommends the development of a tiered approach to safety testing using the criteria: novelty (intended and unintended), potential hazard, and exposure. -Omics technology could be used to inform a tiered approach where more extensive safety assessments would be completed for plants that have differences with potential health or environmental effects and for plants where differences could not be interpreted. Plants with no differences, or plants with understood differences that have no expected health or environmental effect, would not require further testing.

Managing risk

The report reviews the success of risk management measures often mandated by various regulatory authorities. Insect resistance management plans, namely the high dose/refuge strategy, appears to delay the evolution of resistance to Bt in target insects. Products that do not express a high dose to the target pest and low refuge compliance can limit the success of this strategy. Further research is recommended to improve the approaches for delaying resistance to herbicides in weed populations because the current empirical evidence is insufficient to determine the most effective strategy in a given cropping system. To delay the evolution of resistance to herbicides in areas where GE crops with multiple herbicide resistance traits are grown, integrated weed management approaches beyond spraying mixtures of herbicides are needed. For both insect resistance management and herbicide tolerance management, incentives for growers to comply with best management practices are recommended. Regulatory authorities responsible for environmental safety should have the authority to impose continuing requirements (i.e. stewardship plans to mitigate the risk of the evolution of insect and weed resistance) and require environmental monitoring for unexpected effects after a GE crop is commercially released.

The report highlights the importance of proactive communication to the public about how emerging GE technologies or their products might be regulated, and about how new genomics methodologies might be used by regulatory authorities. In addition to communication, public investment is expected to help maximize the potential benefits of GE crops.

During the development of the report, over 22 webinars were presented on topics from RNAi technology to socioeconomic issues. The webinars and other interactive material can be accessed here: http://nas-sites.org/ge-crops/category/pastevents/webinars/.

SOURCE: National Academies of Sciences, Engineering, and Medicine (2016) Genetically Engineered Crops: Experiences and Prospects. Washington, DC: The National Academies Press. Available online: http://nas-sites.org/ge-crops/2016/05/17/report/.

Amendment: Edition 15 (April 2016) Article 3

The article *Update: Ash tree resistance to the emerald ash borer* described the current distribution of the emerald ash borer in Canada as being in 'parts of Ontario and eastern Quebec'. This notice is to highlight that the distribution should be corrected to 'parts of Ontario and western Quebec'.

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