RESEARCH

Shadow Surveys:
How Non-Target Identifications and Citizen Outreach Enhance Exotic Pest Detection

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ABSTRACT: At least 70 exotic invertebrate pests have been newly detected in Washington State since 1990, based on records from the Washington State Department of Agriculture (WSDA) or other published accounts. Most of those species are apparently established. Pests were first detected in multiple ways, including formal surveys by regulatory agencies, accidental captures in formal surveys, and complaints or questions by average citizens. We assigned the 70 detections to four broad categories to better understand how exotic pest detections are made. Twenty species (28%) were detected as "targets" in a pest or commodity-focused survey performed by a regulatory agency. Fourteen species (20%) were first detected as non-targets, or "by-catch" in surveys for other taxa. Twenty-five species (36%) were first found by private citizens, and the remaining 11 (16%) were detected by non-regulatory biologists. These numbers are evidence of the value of non-target identifications and an educated and engaged public to exotic pest detection. The relative cost-to-benefit ratio of identifying most species collected in pest surveys and of eliciting and supporting engagement by private citizens is low, and both strategies can be important tools for protecting domestic natural and economic resources.

KEYWORDS: By-catch, exotic pest survey, cooperative extension

Exotic pest introductions and movement within North America continue to increase via global trade and domestic transport pathways. Although more than a million significant port interceptions have been made since 1984, numerous pests continue to invade the United States through accidental or deliberate transport (Kim and McPheron 1993, Haack 2001, McCullough et al. 2006, Krcmar 2008, Holmes et al. 2009). The costs of introduced pests are well documented and include threats to agriculture and forestry, home gardening, landscape aesthetics, and native ecosystems (Pimentel et al. 2005, Gandhi and Herms 2010, Aukema et al. 2011, Dosdall et al. 2011). Detecting an exotic pest can complicate export marketing of agricultural and natural resource commodities (Heather and Hallman 2008), and responding to exotic pest threats—established or not—has become a perennial task for natural resource industries, regulatory agencies, commodity groups, and citizens (Follett and Neven 2006, Paini et al. 2010).

Exotic pests are detected through a variety of mechanisms in the United States. The most widely used approach is targeted pest or commodity-based surveys conducted yearly by federal and state resource management or regulatory agencies. Surveys are usually funded through a combination of state and federal money, especially through the Cooperative Agricultural Pest Survey program (CAPS) and §1007 of the Farm Bill, administered by the U.S. Department of Agriculture Animal and Plant Health Inspection Service (USDA-APHIS). These surveys target significant individual pest species (e.g., the cotton seed bug, *Oxycarenus hyalinipennis,* Hemiptera: Oxycarenidae), ecologically similar groups of pests (e.g., exotic wood borers), or groups of pests associated with a specific commodity (e.g., citrus pests) (see Table 1 for examples of regularly fielded surveys).

Risk-based assessments are used to identify potential survey targets, to most strategically allocate limited survey and detection resources, and to avoid disrupting or impeding international trade (NPB 1999, Heather and Hallman 2008). Survey targets are selected based on a combination of likelihood of introduction, likelihood of establishment, and the potential damage to economic and/or natural resources (NPB 1999, Passoa 2009, McCullough et al. 2006). Target-based approaches also dominate the screening protocols for agricultural pests; generally, being able to reject a collected specimen as a "non-target" (i.e., anything other than the target species), whether pestiferous or not, is sufficient (USDA 2013). Nonetheless, discovering unanticipated exotic pests in a regular survey for a specific target is potentially an important detection pathway. Additionally, many introduced pests have been first detected by private citizens, including landscapers, off-duty biologists, Master Gardeners, and concerned homeowners or producers (Magarey et al. 2009, Waugh 2009).

With several approaches available for detecting introduced pest species, it is worthwhile to examine the relative contribution of each to our detection successes. Such information may help state and federal agencies better understand the intersections of detection methods, and coordinate, plan, prioritize, and fund detection approaches. To partially address this problem, we analyzed data from pest detections made in Washington State over a 24-year period to look for trends in pest detection.

Materials and Methods

All exotic pest detections in Washington State involving WSDA made between 1990 and 2014 were reviewed and assigned to one of four primary detection categories: 1) detected as the target of a pest survey; 2) detected as a non-target in a pest survey; 3) detected by a professional biologist outside of *regulatory* survey activities; 4) detected by private citizens who are not biologists by trade or training. The year 1990 was chosen as a start date because relatively complete records were readily available in our agency database, and because WSDA had a fairly extensive pest survey program by this time. A review of the literature was also conducted to discover other exotic pests detected in Washington during this time period, with any discovered assigned to the same categories. For the purpose of this paper, a "targeted survey" includes both surveys for a single pest species and broad surveys targeting higher taxa and/or host-associated fauna (e.g., Tortricidae associated with *Malus*). The list of introduced species used for this analysis is limited to those that arguably have an economic impact in the traditional "pest" sense, and thus excludes some important ecologically disruptive species whose impacts on human activities are still tenuous; e.g., *Myrmica specioides* (Jansen and Radchenko 2009) or *Nebria brevicollis* (LaBonte 2011). For the purposes of this analysis, "exotic" pests also include those originating from outside the Pacific Northwest, yet native to North America.

Results

We found 70 new pest detections in Washington State tracked by WSDA or reported in the literature between 1990 and 2014 (Table 1, Fig. 1). Twenty species were detected in a regulatory survey for the given taxon, targeting either a specific pest (e.g., *Synanthedon myopaeformis*) or a broader commodity- or ecologically based group (e.g., exotic Tortricidae). Fourteen detections were non-target pests detected during official surveys. Eleven detections were made by professional biologists outside of regulatory survey activities, and 25 detections were made by the general public. Of the general public detections, nine were communicated directly to WSDA, and 16 were communicated to Washington State University (WSU) Extension.

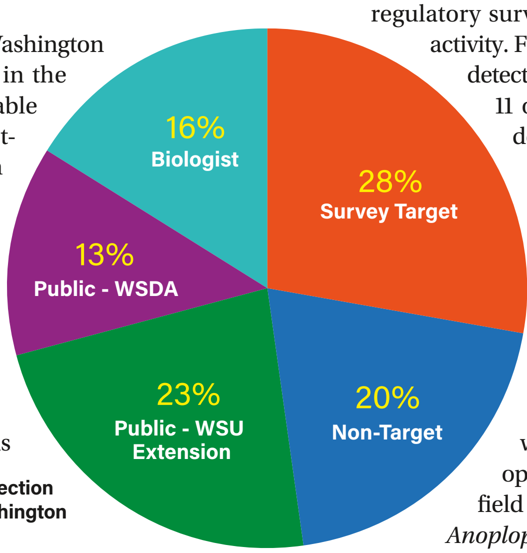

Fig. 1. Relative contribution of different detection pathways to exotic pests detected in Washington State, 1990-2014.

Discussion

Exotic pest introductions into the United States will continue with expanding global trade. At the same time, continuing budget cuts and contracting programs create new challenges for regulatory and management agencies executing their mandates. Not all established pests result in significant government action or market penalties, but even relatively innocuous pests can result in economic costs and increased insecticide use (Raupp et al. 1988, Coffelt and Schultz 1990). Given this ongoing threat of introduction and the socio-political environment, it is important to maximize every opportunity for exotic pest detection. Two detection strategies supported by the data in this paper that appear to significantly improve the likelihood of detecting exotic pests are regular examination of non-target specimens collected in typical pest surveys, and increased financial and institutional support for citizen-based "survey" activities or networks connecting citizens with trained biologists.

Targeted surveys will likely remain the dominant pest detection mechanism in most states, in an effort to focus on the most damaging pests and maximize limited budgets (Stephenson et al. 2003, Lodge et al. 2006). Even commodity-based surveys emphasizing multiple pests (e.g., exotic wood-boring insects) typically focus on only a subset of the potential target pests based on perceived risk. For example, the APHIS Grape Commodity Pest Guidelines emphasize seven out of 12 listed arthropod pests (Sullivan and Jones 2010), with similar guidelines and limitations applied to other commodity-based surveys (e.g., Sullivan and Kalaris 2012).

Despite this, there is good reason to believe that general faunal surveys are the most thorough approach to improve knowledge of both exotic and native species (e.g., deWaard et al. 2009, Brown et al. 2010, Cotterill and Foissner 2010), but funding opportunities for such surveys are rare. A substitute for general surveys that might be more implementable is regular and thorough analysis of by-catch or non-targets collected in typical pest surveys (also see Buchholz et al. 2011). The evidence we present here illustrates the potential value of this approach; 41% of the 34 exotic insect species detected in a regulatory survey were not the target of the survey activity. Furthermore, of the 20 species that were detected during a targeted pest survey, at least 11 of those (16% of total detections) were detected in fairly general surveys without specifically named target species. An Early Detection and Rapid Response pilot program established in 2002 to monitor introduced bark and ambrosia beetles made a point of identifying all specimens collected, and recorded several new national and state records in its first five years (Rabaglia et al. 2008). Astonishing surprises can occur when agency staff maximize detection opportunities afforded by their significant field time. During a 2005 WSDA survey for *Anoplophora chinensis*, one technician noted

Fig. 2. An aggregation of *Cernuella virgata* was discovered by an alert technician in Tacoma, WA, during a wood-boring beetle survey.

an unusual abundance of snails at one field site. By taking the time to collect and identify these snails—in the midst of a beetle survey—a massive infestation of *Cernuella virgata* was discovered at a major port area (Fig. 2).

Predicting the pest potential of introduced species has an imperfect history. While life history traits and known pestiferous activity help identify many prominent threats (Kolar and Lodge 2001, 2002), some species will be missed (Bishop and Hutchings 2011). Neither *Solenopsis invictus* or *Myrmica rubra* are considered significant pests in their native range, yet they are problematic in North America (Buren et al. 1974, Groden et al. 2005). Possibilities for early detection of similar unanticipated invaders will be enhanced when administrative and financial support is given to broader analysis of exotic pest surveys, and the likelihood of detecting introduced species with as-yet small populations will be increased (Barry 2004, Hayes et al. 2005).

Identifying and collecting data from non-target catches also fills gaps in our current knowledge of regional faunae and helps develop taxonomic expertise and knowledge (Buchholz et al. 2011). Poor understanding of even the native fauna in general has been identified as a major barrier to effective early detection (Lodge et al. 2006). Dwindling taxonomic knowledge of many taxa is a significant problem, particularly for invertebrate groups (Lodge et al. 2006). Novel technological solutions will help alleviate this problem (e.g., deWaard et al. 2009, Crabo et al. 2012, Gilligan and Epstein 2012), but there will still be a need for skilled taxonomists, particularly when dealing with degraded specimens that are typical of agricultural pest surveys. Support for non-target examinations will not only result in new detections and expanded knowledge of regional fauna (e.g., Peterson et al. 2007, Strange et al. 2011, Looney et al. 2012b), but provide continuous training challenges and skill development for taxonomists and identifiers.

The high costs of fielding a pest survey make it prudent to examine non-target catches in as many traps as possible. The majority of survey cost is allocated to purchasing traps, hiring field personnel, and trap deployment, checking, and retrieval. The in-house costs of processing traps and identifying target and non-target species are small by comparison. As an example, the WSDA Pest Program budgeted approximately $1,435,000 to support field surveys for various arthropod pests in fiscal year 2012. That budget supported surveys for gypsy moth and other exotic defoliators, exotic grape pests, wood-boring insects, exotic snails, and experimental work with *Cerceris fumipennis* as a buprestid detection tool. Surveys ran from May through October, depending on the target, with more than 27,000 traps placed and more than 25,250 visual inspections conducted throughout the state. Approximately $287,000 was budgeted for taxonomic and laboratory support, including federal funding for a Lepidoptera screening center that processed traps from six western states. This taxonomic capacity was about 16% of the total spent on detecting and delimiting arthropod pests, the majority of expenditures funding field operations and administrative support instead.

This was sufficient to examine thousands of traps and samples and identify more than 25,000 specimens. In our experience, examining non-targets does not always require significantly more time or money beyond that already budgeted for target screening. Most specimens from bucket or sticky card traps arrive in poor condition, and require dissection or other processing before they can be effectively screened. Once this occurs, identification is typically quickly and easily made by a trained taxonomist, and any difficult or unknown specimens can simply be put aside for follow-up analysis. Taking time to consider and subsequently analyze select non-target specimens enhances our collective biological knowledge, and also increases the return on spent public dollars.

The results reported here emphasize the value of involved and informed citizens. Fourteen of the exotic pests reported here came from private citizens. Land-grant universities are mandated by the 1914 Smith-Lever Act to provide extension and outreach activities, and generate a significant pool of trained volunteers and professional audiences to assist regulatory agencies in exotic pest detection. Participants in the WSU Master Gardener Program are often first to encounter a new pest, frequently at community workshops and plant diagnostic clinics where the general public submits plant and pest problems (e.g., Murray et al. 2016). In 2012, 4,895 Master Gardeners made more than 266,000 contacts through clinics, classes, and workshops. During the same year, the WSU Urban IPM Program and Pesticide Education Program offered education to more than 5,600 licensed pesticide applicators, including regular updates about new pest threats. These professional groups often encounter newly introduced pests and are regularly updated with new pest information and concerns at training events. During a 1991 class, a ranger at Peace Arch Park in Blaine, WA, learned of a European cherry pest in British Columbia: *Enarmonia formosana*, the cherry bark tortrix. The following day, the ranger

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Table 1. Chronological list of exotic pests detected within Washington State between 1990 and 2014.

Order: Family	Species	Year Detected	Detection Pathway[1]	Notes / References
Lepidoptera: Tortricidae	*Enarmonia formosana* (Scopoli)	1991	Public-WSDA	Park ranger detection
Lepidoptera: Tortricidae	*Notocelia rosaecolana* (Doubleday)	1991	WSDA-NT	*Enarmonia formosana* survey
Lepidoptera: Yponomeutidae	*Yponomeuta padella* (L.)	1993	WSDA Survey	*Yponomeuta padella* survey
Lepidoptera: Gelechiidae	*Recurvaria nanella* (Denis & Schiffermüller)	1994	WSDA Survey	Exotic apple defoliators survey
Lepidoptera: Geometridae	*Pasiphila rectangulata* (L.)	1994	WSDA Survey	Exotic apple defoliators survey
Lepidoptera: Geometridae	*Hemithea aestivaria* (Hübner)	1994	WSDA Survey	Exotic apple defoliators survey
Lepidoptera: Tortricidae	*Pandemis cerasana* (Hübner)	1994	WSDA Survey	Exotic apple defoliators survey
Lepidoptera: Tortricidae	*Pandemis heparana* (Denis & Schiffermüller)	1994	WSDA Survey	Exotic apple defoliators survey
Lepidoptera: Tortricidae	*Acleris holmiana* (L.)	1994	WSDA Survey	Exotic apple defoliators survey
Lepidoptera: Tortricidae	*Hedya nubiferana* (Haworth)	1994	WSDA Survey	Exotic apple defoliators survey
Lepidoptera: Tortricidae	*Archips fuscocupreana* Walsingham	1995	WSDA-NT	*Yponomeuta padella* survey
Coleoptera: Curculionidae	*Xyloterinus politus* (Say)	1996	WSDA-NT	*Tomicus piniperda*, *Ips typographus*, *Hylastes opacus* survey Mudge et al. 2001
Coleoptera: Curculionidae	*Xyleborinus attenuatus* (Blandford)	1996	WSDA-NT	*Tomicus piniperda*, *Ips typographus*, *Hylastes opacus* survey Mudge et al. 2001
Coleoptera: Curculionidae	*Cyclorhipidion bodoanum* (Reitter)	1996	WSDA-NT	*Tomicus piniperda*, *Ips typographus*, *Hylastes opacus* survey Mudge et al. 2001
Coleoptera: Elateridae	*Melanotus cete* Candèze	1996	WSDA-NT	*Tomicus piniperda*, *Ips typographus*, *Hylastes opacus* survey
Hymenoptera: Tenthredinidae	*Pristiphora rufipes* Serville	1996	Public-WSU Ext	Public complaint, ornamental damage Looney et al. 2016
Coleoptera: Elateridae	*Agriotes obscurus* (L.)	1997	Biologist	Carabidae survey Vernon and Päts 1997
Lepidoptera: Tineidae	*Haplotinea ditella* (Pierce & Metcalfe)	1997	WSDA-NT	*Enarmonia formosana* survey
Lepidoptera: Depressariidae	*Carcina quercana* (Fabricius)	1997	Public-WSU Ext	Public complaint, ornamental damage
Lepidoptera: Tortricidae	*Notocelia cynosbatella* (L.)	1997	Biologist	General collecting activities
Coleoptera: Micromalthidae	*Micromalthus debilis* LeConte	1998	Public-WSDA	Public complaint, nuisance pest Mudge et al. 2001
Lepidoptera: Tortricidae	*Gypsonoma aceriana* (Duponchel)	1998	WSDA Survey	General exotic pest survey Miller and LaGasa 2001
Hymenoptera: Tenthredinidae	*Nematus lipovskyi* Smith	1998	Public-WSU Ext	Public complaint, ornamental damage Looney et al. 2016
Lepidoptera: Tortricidae	*Clepsis spectrana* (Treitschke)	1998	WSDA-NT	*Pandemis heparana* survey
Coleoptera: Chrysomelidae	*Oulema melanopus* (L.)	1999	Public-WSU Ext	Grower detection
Coleoptera: Cerambycidae	*Phymatodes testaceous* (L.)	1999	ODA Survey	Wood-boring insect survey LaBonte et al. 2005
Diptera: Tipulidae	*Tipula oleracea* L.	1999	WSDA Survey	*Tipula oleracea* survey
Hymenoptera: Vespidae	*Polistes dominula* (Christ)	1999	Biologist	Landolt and Antonelli 1999
Lepidoptera: Argyresthiidae	*Argyresthia conjugella* Zeller	1999	WSDA Survey	Exotic pest survey
Coleoptera: Elateridae	*Agriotes lineatus* (L.)	2000	WSDA Survey	*Agriotes* spp. survey Vernon et al. 2001
Lepidoptera: Tortricidae	*Archips podana* (Scopoli)	2000	WSDA-NT	*Ostrinia nubialis* survey
Coleoptera: Chrysomelidae	*Pyrrhalta viburni* (Paykull)	2001	Public-WSU Ext	Public complaint, ornamental damage Murray et al. 2016
Hemiptera: Rhyparochromidae	*Rhyparochromus vulgaris* (Schilling)	2001	Public-WSDA	Public complaint, nuisance Henry 2004
Diptera: Culicidae	*Ochlerotatus japonicus* (Theobald)	2001	DOH Survey	Western Washington mosquito survey Roppo et al. 2004
Acari: Eriophyidae	*Calepitrimerus vitis* (Nalepa)	2002	Biologist	Prischmann and James 2005
Lepidoptera: Noctuidae	*Noctua pronuba* (L.)	2004	Public-WSU Ext	Slightly older specimens known from San Juan County Crabo et al. 2012

Order: Family	Species	Year Detected	Detection Pathway[1]	Notes / References
Thysanoptera: Thripidae	*Ceratothrips ericae* (Haliday)	2004	USDA Survey	Northern border exotic pest survey
Stylommatophora: Hygromiidae	*Cernuella virgata* (Da Costa)	2005	WSDA-NT	*Anoplophora chinensis* survey
Lepidoptera: Tortricidae	*Cydia* sp.[2]	2005	WSDA-NT	*Ostrinia nubialis* survey LaGasa and Passoa 2007
Stylommatophora: Hygromiidae	*Candidula intersecta* (Poiret)	2006	WSDA Survey	Exotic snail survey
Hemiptera: Oxycarenidae	*Metopoplax ditomoides* (Costa)	2006	Public-WSU Ext	Public complaint, bugs in walls
Hemiptera: Rhyparochromidae	*Raglius alboacuminatus* (Goeze)	2006	Public-WSDA	Public complaint, nuisance pest
Hymenoptera: Formicidae	*Myrmica rubra* (L.)	2006	Public-WSU Ext	Pubic complaint, stinging ants in park[3]
Lepidoptera: Sesiidae	*Synanthedon myopaeformis* (Borkhausen)	2006	WSDA Survey	*Synanthedon myopaeformis* survey
Hymenoptera: Tenthredinidae	*Pristiphora geniculata* (Hartig)	2009	Public-WSU Ext	Public complaint, ornamental damage Looney et al. 2016
Thysanoptera: Thripidae	*Thrips flavus* Schrank	2006	Biologist	General collecting activities
Coleoptera: Curculionidae	*Trypodendron domesticum* (L.)	2007	WSDA Survey	*Trypodendron* spp. survey
Diptera: Cecidomyiidae	*Contarinia quinquenotata* (Loew)	2007	Public-WSU Ext	Public complaint, ornamental damage
Lepidoptera: Noctuidae	*Chloridea virescens* (Fabricius)	2007	Biologist	Landolt 2009
Lepidoptera: Noctuidae	*Hecatera dysodea* (Denis & Schiffermüller)	2007	Biologist	Landolt et al. 2010
Hemiptera: Tingidae	*Stephanitis pyrioides* (Scott)	2007	Public-WSU Ext	Public complaint, ornamental damage
Hymenoptera: Diprionidae	*Neodiprion sertifer* (Geoffroy)	2008	Public-WSDA	Question from pest control operator Looney et al. 2016
Coleoptera: Scarabaeidae	*Amphimallon majale* (Razoumowsky)	2008	WSDA-NT	*Popillia japonica* survey
Coleoptera: Curculionidae	*Pityophthorus juglandis* Blackman	2008	Public-WSU Ext	Cranshaw 2011
Lepidoptera: Sesiidae	*Synanthedon scitula* (Harris)	2008	WSDA-NT	*Synanthedon myopaeformis* survey Looney et al. 2012b
Coleoptera: Curculionidae	*Ips paraconfusus* Lanier	2009	Public-WSU Ext	Public complaint, tree damage Murray et al. 2013
Diptera: Drosophilidae	*Drosophila suzukii* (Matsumura)	2009	Biologist	Research and extension station
Hemiptera: Pentatomidae	*Halyomorpha halys* (Stål)	2010	Public-WSDA	Citizen responding to news story
Hymenoptera: Tenthridinidae	*Monsoma pulveratum* (Retzius)	2010	Biologist	General collecting activities Looney et al. 2012c
Lepidoptera: Argyresthiidae	*Argyresthia pruniella* (Clerck)	2010	WSDA Survey	*Argyresthia pruniella* survey
Lepidoptera: Galacticidae	*Homadaula anisocentra* Meyrick	2010	WSDA-NT	*Lobesia botrana* survey
Coleoptera: Curculionidae	*Orchestes alni* (L.)	2011	Biologist	General collecting activities Looney et al. 2012a
Hymenoptera: Diprionidae	*Gilpinia hercyniae* (Hartig)	2011	Biologist	General collecting activities Looney et al. 2016
Coleoptera: Chrysomelidae	*Lilioceris lilii* (Scopoli)	2012	Public-WSU Ext	Public complaint, ornamental damage Murray et al. 2016
Hymenoptera: Diprionidae	*Diprion similis* (Hartig)	2012	Public-WSDA	Public complaint, tree damage Looney et al. 2016
Hymenoptera: Tenthredinidae	*Heterarthrus vagans* (Fallén)	2012	WSDA Survey	Exotic sawfly survey Looney et al. 2016
Hymenoptera: Tenthredinidae	*Monostegia abdominalis* (Fabricius)	2013	Public-WSU Ext	City parks employee noted insect outbreak on noxious weed host Looney et al. 2016
Coleoptera: Buprestidae	*Agrilus cuprescens* (Menetries)	2014	Public-WSDA	Citizen picture posted to bugguide.net Westcott et al. 2015
Hemiptera: Lygaeidae	*Arocatus melanocephalus* (Fabricius)	2014	Public-WSU Ext	Public complaints, nuisance pests
Hemiptera: Pentatomidae	*Nezara viridula* (L.)	2014	Public-WSDA	Multiple citizen questions about an un-recognized stink bug

[1] Abbreviations are Public-WSDA: public detection first communicated to WSDA, Public-WSU-Ext: Public detection first communicated to WSU Extension, WSDA-NT: non-target detected in a WSDA survey, DOH: Washington Dpt. of Health, ODA: Oregon Dpt. of Agriculture.

[2] Initially identified as *Cydia coniferana*; recent molecular data suggest it may be a different introduced species.

[3] Wetterer and Radchenko (2011) note a specimen collected in 1988, previously unreported and housed in a collection in Florida.

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examined the old flowering cherries at the park, discovered *E. formosana* activity, and alerted WSDA (Fig. 3).

Opportunities and support for extension programs have waned over the past several decades (McDowell et al. 2004). Most recently, extension programs have adapted to cuts during the Great Recession by increasing other revenue sources: accessing grants, charging fees, and establishing other funding partnerships (Serenari et al. 2013). Changing funding sources directly impacts the focus of the programs offered, which may threaten Master Gardener and similar education-based programs. Rather than eviscerate such programs, developing them and integrating new technologies can increase early detections and reduce response time.

The contribution of citizen surveyors has been formalized in the creation of several citizen-science survey programs. A citizen survey effort using *Cerceris fumipennis* as a tool to detect exotic buprestids generated one of the first two records of *Agrilis planipennis* in Connecticut (Rutledge et al. 2013). Smartphone apps (e.g., the Pacific Northwest Early Detection Network, http://apps.bugwood.org) and internet sites that encourage citizens to report exotic species are increasingly widespread, even if still nascent. The Texas Invasives program is just one example of many similar state initiatives that provide citizen scientists with training, collection equipment, and data management tools (www.texasinvasives.org). In a five-year period, the program trained 702 data collectors and logged 8,466 species observations (Waitt and Gallo 2010). In addition to detection and range expansion, citizen scientists have provided significant contributions to exotic pest management. For example, amateur entomologists and citizen scientists helped determine the distribution of *Noctua pronuba* throughout the NE United States, as well as the host range of the viburnum leaf beetle, *Pyrrhalta viburni* (Passoa and Hollingsworth 1996, Weston et al. 2007). BugGuide (http://bugguide.net) is a continually expanding forum that connects citizens with expert and amateur taxonomists to help accurately identify insects, generating novel behavioral observations and expanding known ranges (e.g., Hamilton 2011, Strange et al. 2011, Looney et al. 2012c, Harrison et al. 2016).

The data we present here are limited in scope and raise many questions. To begin with, it's not clear if the detections made by examining non-target catches and those contributed by citizens are unique to Washington, although the potential value of the letter has been highlighted by other researchers (e.g., Dowell et al. 2016). In terms of non-target catches, the argument is at least partially semantic. "Non-target" is a moving target, and calling one bark beetle collected in a survey for a different bark beetle a "non-target" might be splitting hairs. The prominence of citizen detections in these data could merely indicate institutional gaps in Washington that create space for such discoveries. Other states may habitually field surveys with greater taxonomic breadth, or spend more time examining non-target catches, leaving limited opportunity for citizens to make first detections. Trends in state-level detection methods and the relationship between funding levels for citizen-based programs and exotic pest detection rates is a potentially rich and illuminating area for further exploration. A reviewer of an earlier draft also wondered if some taxa were more likely to be detected by citizens and others by regulatory specialists. It seems logical that showy and brightly colored insects would be easier for non-taxonomists to recognize than small and difficult-to-identify taxa. Even so, non-taxonomists frequently recognize other signs of exotic insects, such as population outbreaks or unusual plant damage (Mudge et al. 2001, Murray et al. 2013). Understanding the taxonomic breadth of citizen detections is a research question that begs for a thorough analysis in order to best marshal citizen contributions.

Despite the limitations of these data and the narrow focus on Washington State, it seems clear—indeed, nearly tautological—that when survey captures are screened for more than just pre-determined pests and communication between regulatory agencies and citizens is enhanced, the chances of detecting exotic species are higher. Opportunities to capitalize upon these detection pathways should be identified and further researched. Better understanding the different contributions of citizens and extension personnel, researchers, and regulators will

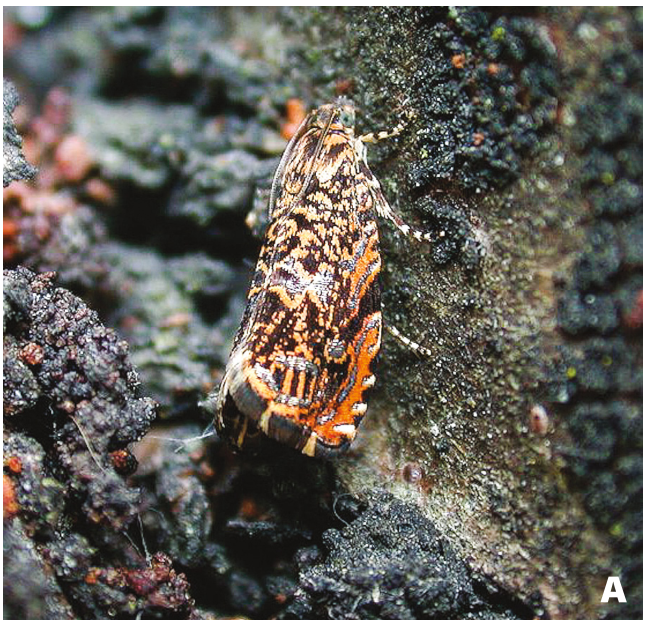

Fig. 3. ***Enarmonia formosana*, an aggressive wood-boring tortricid moth (a), was discovered by a park ranger along the Washington–British Columbia border soon after the ranger learned about it in a pesticide relicensing lecture. Extensive feeding by this wood-boring moth (b) has devastated cherry trees in western Washington.**

allow efficient incorporation of each in national and state-level pest detection programs, and perhaps improve communication between practicing scientists. Non-target detections are currently documented haphazardly, with a dearth of national databases to coordinate information collected by the various states and agencies (see Spears and Ramirez, 2015, for further discussion of systematically capturing data from by-catch). With strategic institutional and financial support, agencies can bring these irregular survey approaches out of the shadows and maximize our collective survey efforts.

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