Genome / Génome

DNA Barcodes for Bio-surveillance: Regulated and Economically Important Arthropod Plant Pests

Journal:	*Genome*
Manuscript ID	gen-2016-0024.R2
Manuscript Type:	Review
Date Submitted by the Author:	16-Jul-2016
Complete List of Authors:	Ashfaq, Muhammad; University of Guelph Biodiversity Institute of Ontario Hebert, Paul; Biodiversity Institute of Ontario,
Keyword:	species identification, cryptic taxa, invasive species, quarantine, pest management

DNA Barcodes for Bio-surveillance: Regulated and Economically Important Arthropod Plant Pests

Muhammad Ashfaq* and Paul D.N. Hebert

Centre for Biodiversity Genomics, Biodiversity Institute of Ontario, University of Guelph, Guelph, ON, Canada

* Corresponding author:

Muhammad Ashfaq

Centre for Biodiversity Genomics, Biodiversity Institute of Ontario, University of Guelph, Guelph, ON N1G 2W1, Canada

Email: mashfaq@uoguelph.ca

Phone: (519) 824-4120 Ext. 56393

Abstract

Many of the arthropod species that are important pests of agriculture and forestry are impossible to discriminate morphologically throughout all of their life stages. Some cannot be differentiated at any life stage. Over the past decade, DNA barcoding has gained increasing adoption as a tool to both identify known species and to reveal cryptic taxa. Although there has not been a focused effort to develop a barcode library for them, reference sequences are now available for 77% of the 409 species of arthropods documented on major pest databases. Aside from developing the reference library needed to guide specimen identifications, past barcode studies have revealed that a significant fraction of arthropod pests are a complex of allied taxa. Because of their importance as pests and disease vectors impacting global agriculture and forestry, DNA barcode results on these arthropods have significant implications for quarantine detection, regulation, and management. The current review discusses these implications in light of the presence of cryptic species in plant pests exposed by DNA barcoding.

Key words: Species identification, cryptic taxa, invasive species, quarantine, pest management

Introduction

Thousands of arthropod species either directly attack economically important plants or transmit viral and bacterial diseases, imposing massive costs on agriculture and forestry. For example, the widely distributed diamondback moth, *Plutella xylostella,* causes $US4B-5B in damage to crops each year (Zalucki et al. 2012). The economic losses due to arthropods are increasing as new species gain pest status, often following human-mediated range expansions which, in the absence of natural enemies (Liebhold et al. 2013), can lead to population explosions that move a species from non-pest in its native range to pest in newly colonized areas (Aukema et al. 2011). The number of alien species continues to rise with arthropods representing the dominant component of this cross-border traffic, for example in Europe, as documented by the European Environment Agency (http://www.eea.europa.eu/). Five major databases track the most important arthropod pests and disease vectors of agriculture and forestry; they are maintained by the Canadian Food Inspection Agency (CFIA) (www.inspection.gc.ca), the European and Mediterranean Plant Protection Organization (EPPO) (www.eppo.int), the Global Invasive Species Database (GISD) (http://www.iucngisd.org), the National Agricultural Pest Information System (NAPIS) (https://napis.ceris.purdue.edu) and the United States Department of Agriculture - Animal and Plant Health Inspection Service (USDA-APHIS) (www.aphis.usda.gov) (accessed 3-5 January 2016). These databases, which include regulated, invasive and economically important plant pests with a focus on species important in Europe and North America, have been used to compile unified pest lists (Frewin et al. 2013). Since significant progress on DNA barcoding of plant pests has also been made in these regions, the current article draws the core information from these five sources as a basis for a discussion of cryptic species and their implications for DNA barcode applications. All but 21 of the 409 arthropod pest species on these lists belong to five insect orders (Coleoptera, Diptera, Hemiptera, Lepidoptera, Thysanoptera) (Table S1). An additional 36 cryptic pest species reported in literature but not included in the five databases are considered in this article (Table S1). Taxonomic difficulties continue to constrain the regulation of pest arthropods as indicated by the fact that 18 of the entries on these lists are only identified to a genus (Table S1) while some with a species designation are known to be a species complex (Mally et al. 2015). These taxonomic complexities have provoked growing interest in the adoption of DNA-based approaches for species recognition, creating interesting challenges for traditional approaches to regulatory compliance (Jörger and Schrödl 2013).

The balance of this article begins by considering the effectiveness of DNA barcoding in identifying arthropods and in revealing cryptic species. It then proceeds to consider past studies of cryptic diversity in pest arthropods, before concluding with a discussion of the implications of DNA barcoding for pest regulation, management and quarantine.

Effectiveness of DNA barcodes for arthropod identification

The efficacy of DNA barcoding (Hebert et al. 2003*a*) for specimen identification and species discovery has stimulated an international research program which has generated a barcode reference library for more than 250,000 described species of animals, fungi and plants, data which resides in BOLD, the Barcode of Life Data System (Ratnasingham and Hebert 2007). Each of the 4.5 million animal records on BOLD has been assigned to a BIN, a Barcode Index Number (Ratnasingham and Hebert 2013), generating 452K BINs, predominantly insects (315K) (accessed 21 April 2016). Because BINs show strong congruence with species designated through past morphological study (Pentinsaari et al. 2014; Zahiri et al. 2014, Mutanen et al. 2015), they can be viewed as species proxies (Telfer et al. 2015) to facilitate the assessment of large-scale biodiversity patterns (Blagoev et al. 2015) and the detection of cryptic species complexes (Ashfaq et al. 2015; Kekkonen and Hebert 2014). The use of barcode data to identify species (Rakauskas and Basilova 2013) as opposed to BINs requires the species in question be represented in the barcode reference library (Ekrem et al. 2007). Because the barcode reference library now includes records for many agricultural and forestry pests (Ashfaq et al. 2014; Foottit et al. 2014; Raupach et al. 2014), newly encountered specimens of these species can be identified through barcode analysis. As well, the extension of DNA barcoding protocols onto next-generation sequencing (NGS) platforms (Shokralla et al. 2014) is enabling metabarcoding studies which permit large-scale assessments of species composition (Taberlet et al. 2012), an approach of high importance in monitoring plant pests.

DNA barcoding has a strong track record in delivering species-level identifications for the five insect orders with the most pest species - Coleoptera (Rougerie et al. 2015; Woodcock et al. 2013), Diptera (Nagy et al. 2013; Smit et al. 2013), Hemiptera (Park et al. 2011*b*; Raupach et al. 2014), Lepidoptera (Ashfaq et al. 2013; Janzen et al. 2005) and Thysanoptera (Rebijith et al. 2014; Iftikhar et al. 2016). For example, 92.2% of 3514 species of European beetles were assigned to a distinct BIN that coincided with a known morphological species, while most of the other species were assigned to two or three BINs, suggesting they represent cryptic species complexes (Hendrich et al. 2015). Work on Diptera has similarly validated the effectiveness of

DNA barcoding for the identification of species in this order, including some of the most important agricultural pests, such as fruit flies (Virgilio et al. 2012) and leafminers (Amin et al. 2014). Another study that examined 1849 species of Canadian Hemiptera assigned these species to 1867 BINs with high correspondence between species and BINs, but also revealed 27 species with high divergences suggestive of cryptic species complexes (Gwiazdowski et al. 2015). Lepidoptera, the most intensively studied order, is represented by more than 100,000 BINs on BOLD. Work on this group has demonstrated the efficacy of DNA barcoding in identifying known species (Dinca et al. 2015; Wilson et al. 2013) and in revealing cryptic species complexes (Burns et al. 2008; Huemer et al. 2014*a*). It has also shown that there is very limited geographic variation in barcode sequences in populations of most species so increased geographic scale does not reduce the success of species identification (Lukhtanov et al. 2009; Huemer et al. 2014*b*, Candek and Kuntner 2015). However, in certain groups, such as diving beetles of the tribe Agabini (Bergsten et al. 2012), the correlation between genetic and geographic distances is strong enough to impact the success of species identification unless sampling of each species is fairly comprehensive. Studies on Lepidoptera have further shown the way in which DNA barcoding can challenge current taxonomic boundaries, can shift understanding of distributions (Rougerie et al. 2014) and can expose inconsistent usage of species names (Mutanen et al. 2012). Finally, work on Lepidoptera has confirmed that BINs are a strong proxy for species. For example, 93% of 215 species of European geometrid moths showed a perfect correspondence between BINs and known species (Hausmann et al. 2013).

The effectiveness of DNA barcoding in species recognition has also been established for Acari, the other major group of arthropods with important plant pests (Young et al. 2012). For example, it allowed resolution of the species composition of spider mites in agricultural settings in Vietnam (Hinomoto et al. 2007) and Europe (Ros and Breeuwer 2007). These studies have stimulated the development of barcode reference libraries, and have also revealed overlooked species in this group of pests (Matsuda et al. 2013).

A search on BOLD (December 22, 2015) revealed sequence coverage for 314 (269 public) of the 409 species (77%) of plant arthropod pests (Table 1). Although sequences and BIN assignments for 45 species on BOLD were private, they were included as taxa with coverage. Coverage for species of Diptera (90%) and Lepidoptera (87%) was higher than that for Coleoptera (71%) and Hemiptera (64%). Table 2 details the number of barcode records, BINs, and intraspecific divergence values for the pest species with five or more sequences on BOLD. All but 18 of these 314 species possessed at least one barcode-compliant (>500 bp, <1% ambiguous bases, no stop-codon or contamination) record and 1/3 of the species (61/178) represented by five or more records showed a BIN split, suggesting that they represent a species complex (Table 2, Table S1). However, the possibility that some of these cases may reflect misidentifications or introgression (Harrison and Larson 2014) cannot be ruled out without detailed study on a case-by-case basis.

Incomplete resolution or flawed taxonomy?

DNA barcoding has failed to separate some congeneric species of important pests such as the tephritid fruit flies *Bactrocera occipitalis* and *B. philippinensis* (Sumalde et al. 2013). Another study which examined 193 tephritid species failed to discriminate six species in the *B. dorsalis* complex (*B. dorsalis, B. occipitalis, B. carambolae, B. papaya, B. invadens*, *B. philippinensis*) (Frey et al. 2013; Jiang et al. 2014). This discrepancy between taxonomic assignments and barcode results (Hendrichs et al. 2015) provoked a reevaluation of their taxonomy, work which suggested that at least some of the taxa involved are conspecific (Khamis et al. 2012; Schutze et al. 2012). In fact, a subsequent taxonomic revision synonymized *B. invadens* and *B. papaya* with *B. dorsalis* (Schutze et al. 2015). There are many other cases where pest species on different plants have been assigned to separate species when they likely represent just one taxon. For example, populations of the "mango mealybug" on mango trees in Pakistan were identified to *Drosicha mangiferae* (Latif 1949) while those on forest trees were assigned to *D. stebbingi* (Gul et al. 1997). A barcode study (Ashfaq et al. 2011), supported by results from three other gene regions, did not reveal any genetic divergence between mealybugs on mango and six other fruit and forest trees, supporting an earlier suggestion of their synonymy (Latif 1949).

Cryptic Species

Although the definition of cryptic species is fluid (Jörger and Schrödl 2013), it is generally accepted that lineages with deep mitochondrial divergence without obvious morphological differences are strong candidates (Rivera and Currie 2009). Although divergence patterns in mitochondrial and nuclear genes are sometimes discordant (Humphries et al. 2011), surveys of mitochondrial diversity provide quick insight into species boundaries (Mutanen et al. 2015).

Lineages showing sequence divergence, often termed molecular operational taxonomic units (MOTUs) (Blaxter et al. 2005), have been discriminated by analyzing sequence variation using distance analysis (Schloss and Handelsman 2005), neighbor-joining clustering (Saitou and Nei 1987), phylogenetic trees (Zhang et al. 2013), Bayesian inference (Yang and Rannala 1997), coalescence-based approach (Pons et al. 2006; Fujisawa and Barraclough 2013), barcode-gap analysis (Puillandre et al. 2012) and BINs (Ratnasingham and Hebert 2013). However, there is a growing trend to integrate multiple methods (Ashfaq et al. 2015; Blagoev et al. 2015; Kekkonen et al. 2015) and multiple markers (Jörger et al. 2012; Mrinalini et al. 2015) to assess MOTU diversity. The results from such analyses have frequently been helpful in resolving taxonomic problems and in estimating species richness and abundance (Mutanen et al. 2013; Stahlhut et al. 2013; Unterseher et al. 2011). However, the use of a single, standardized, marker has the advantage of simplifying molecular identification (Savolainen et al. 2005), a valuable feature for pest managers and regulators in field applications (Armstrong and Ball 2005). Reflecting the ease of recovering sequence information, and access to refined analytical tools, the discovery of new cryptic species is now commonplace in many animal groups.

Cryptic species have important implications for taxonomic, evolutionary, and biodiversity studies, but their presence in pest taxa also has economic and regulatory implications (Piffaretti et al. 2013; Rebijith et al. 2014). Several studies have considered the impact of cryptic species on pest management (Frewin et al. 2014; Ovalle et al. 2014), biological control strategies (Derocles et al. 2015), the detection of invasive species (Blacket et al. 2015; Li et al. 2015) and quarantine inspections (Kang et al. 2015). The most obvious implications of DNA barcoding relate to its capacity to discriminate the members of cryptic species complexes (Robe et al. 2013). Systems which employ sequence matches to identify specimens are already a reality (MacLeod et al. 2010), allowing the automated detection of regulated species (Lammers et al. 2014). However, in large-scale metabarcoding, standardization of metadata and taxonomic identifications still require consensus (Tedersoo et al. 2015), factors which currently limit the application of this approach in a regulatory context. This gap could be addressed through community action, perhaps via the International Barcode of Life (iBOL) (http://ibol.org) or the Genomics Standards Consortium (http://gensc.org/) model (Yilmaz et al. 2011).

Revealing cryptic species in pest arthropods

The effectiveness of DNA barcoding in revealing overlooked species in global pests like bark beetles, leafminers, gall midges, mealybugs, wireworms, seed borers, gypsy moths, armyworms and thrips is well documented (Table 3). For example, *Liriomyza langei* (Diptera: Agromyzidae), a leafminer pest native to California, is morphologically indistinguishable from the invasive *L. huidobrensis*. However, the two species are easily discriminated by barcoding, a factor which enabled the analysis of their distributions (Scheffer et al. 2014). Similarly, the larvae of *Camptomyia corticalis* and *C. heterobia* which inflict severe damage on the production of shiitake mushrooms are easily separated by their 10.3% barcode divergence (Shin et al. 2013). Aphids are globally important pests and major vectors of many plant diseases, but they are challenging to identify because most of the 3000 species in this family possess striking phenotypic plasticity and life stage diversity. DNA barcoding has proven an effective tool for species discrimination because intraspecific distance is low in most species, averaging just 0.2%, while congeneric distances are high (Foottit et al. 2008). However, some species, such as *Neomyzus circumflexus,* have higher divergences (>3%), suggesting they represent a complex (Table 3). Tussock moths (Lepidoptera: Lymantriidae) are worldwide pests which have been well-studied taxonomically. Nonetheless, DNA barcode studies revealed deep intraspecific divergences in *Lymantria dispar* (3.1%), *L. mathura* (4.7%) and *L. sinica* (2.9%) suggesting possible overlooked species (Table 3). Similarly, DNA barcode results have generally indicated congruence with morphologically recognized species of thrips (Qiao et al. 2012), but cryptic diversity is common with cases of high intraspecific divergence and deep genetic splits in several pest species (Tables 2, 3).

Practical Implications of DNA Barcoding

Pest regulation and management:

DNA barcoding is gaining broad application in integrated pest management (IPM) (Etzler et al. 2014) and bio-surveillance (Jones et al. 2013) programs as the standard method for species identification by 'matching unknown against the known' (Armstrong 2010). This is evidenced by the development of barcode-based kits for the identification of quarantine pests (Jiang-Ling et al. 2015). IPM requires the correct identification of target species and monitoring of its effectiveness often involves diverse stakeholders including farmers, crop pest regulators and quarantine agents. As long as "query" specimens show close sequence similarity to species in the reference library, match-based identifications are effective (Hebert et al. 2003*b*). Although most morphological species show congruence with BINs (Pentinsaari et al. 2014; Zahiri et al. 2014;

Table 1), inconsistencies between morphologically recognized species and the genetic clusters discriminated by BINs are not infrequent. Such discrepancies complicate the identification of their component taxa with implications for pest regulation and management. For example, the whitefly, *Bemisia tabaci,* is now known to be a complex of at least 34 species (Lee et al. 2013) which differ in their invasiveness (De Barro and Ahmed 2011), their capacity to transmit plant pathogens (Chowda-Reddy et al. 2012) and their regional pest status (Ashfaq et al. 2014). Likewise, two pest thrips, *Scirtothrips dorsalis* and *Thrips tabaci,* are species complexes whose members vary in their invasiveness and viral-transmission ability (Dickey et al. 2015; Jacobson et al. 2013). Similarly, root weevil, *Diaprepes abbreviatus*, is a species complex (Ascunce et al. 2008) with 13 BINs that show differing geographic distributions. Any effort to regulate such species complexes as a single entity is inappropriate because it can complicate regulatory compliance and compromise management and control efforts by raising concerns when non-invasive or non-vector species are treated as pests. Although many regulated pest species with barcode records are assigned to a single BIN, about one third on BOLD show a BIN split (Table 1). For example, *Leucinodes orbonalis*, a quarantine pest, is represented by six BINs, with diverse geographic origins. The cross-border movements of species with BIN diversity raise complexities that will often create ambiguity in species matches requiring revisions to quarantine regulations. Conversely, there are cases where different species lack barcode divergence, preventing their discrimination. The most dramatic case involves 20 species in the fruit fly genus *Bactrocera* which share the same BIN. While some of these taxa have recently been synonymized (Schutze et al. 2015) and other cases may reflect misidentifications, it is likely that other cases reflect closely allied species which hybridize. Such cases require more detailed investigation to ascertain if other genetic markers allow their discrimination or reveal that they are actually synonyms.

Since DNA barcoding reliably identifies both immatures and adults (Shin et al. 2013), and can differentiate introduced and native pests (Chown et al. 2008), it has been used to help manage species complexes in agricultural systems (Frewin et al. 2014; Li et al. 2011). Such applications are important because insecticide resistance can vary between closely related species, and even between genotypes of the same species (van Toor et al. 2008). For example, two cryptic whiteflies in the *B. tabaci* complex, *Mediterranean* and *Middle East-Asia Minor 1* (*MEAM1*), differ in their susceptibility to insecticides. A study on the response of mixed populations of these species showed that the *Mediterranean* species prevails under insecticide-based management, but is displaced by *MEAM1* under biological control (Frewin et al. 2014).

Biological control is widely viewed as the optimal pest management strategy, but incorrect identification of either the pest species or its control agent due to cryptic diversity can lead to unpredictable outcomes (Van Lenteren et al. 2003). Because of its capacity to determine host-parasitoid associations (Erlandson et al. 2003), DNA barcoding has been employed to gain a deeper understanding of biological control using natural enemies. For example, Davis et al. (2011) differentiated immatures of *Laricobius rubidus*, a native biological control agent of hemlock woolly adelgid, *Adelges tsugae* (complex of four BINs) from the closely related *L. nigrinus* introduced from Japan while Derocles et al. (2015) examined interactions between a leafminer and its parasitoids to advance biological control. Several studies have revealed unexpected diversity and interactions linked to cryptic diversity. The outcomes of biological control rapidly gain unpredictability (Roderick et al. 2012) when both the control agent and the target are cryptic species complexes, as for example, in the case of the hymenopteran wasp, *Trichogramma japonicum* (3 BINs) which is employed as a control agent for the brinjal borer, *L. orbonalis* (6 BINs).

Quarantine of invasive alien species:

Expansions in the geographic range of insect pests often require a rapid response (Adrion et al. 2014), and DNA barcoding can provide insights beyond those obtained through morphological analysis. For example, aside from enabling the early detection of invasive species (Onah et al. 2015), DNA barcoding can reveal source regions (Bellis et al. 2015) and introduction patterns (Blacket et al. 2015). Nagoshi et al. (2011) used it to monitor introductions of the invasive armyworm species, *Spodoptera litura* and *S. littoralis,* into Florida, while Tyagi et al. (2015) and Wei et al. (2010) detected the first invasions of *Thrips parvispinus* and *Echinothrips americanus*, in India and China. In a similar fashion, DNA barcoding differentiated *Heliothis armigera* from the native *H. zea,* revealing the spread of the former species after its introduction into Brazil (Mastrangelo et al. 2014). More recently, DNA barcoding led to the recognition of a buprestid beetle, *Agrilus ribesi*, whose introduction to North America had been overlooked for a century (Jendek et al. 2015). Barcoding has also been used to detect invasive tephritid fruit flies in Nigeria (Onah et al. 2015), leafminers in Papua New Guinea (Blacket et al. 2015) and Italy (Bernardo et al. 2015), a stink bug (*Halyomorpha halys*) in Europe (Cesari et al. 2015) and a cotton bug, *Oxycarenus hyalinipennis* in Florida (Nagoshi et al. 2012). Based on its effectiveness in species identification, the Quarantine Barcode of Life project (www.qbol.org) worked towards establishing DNA barcoding as the core technology for identifying quarantine organisms in support of plant health, and to gain its acceptance by the pest regulators as the standard method for the identification of plant pests (van de Vossenberg et al. 2013). Since DNA barcoding meets the minimum standards (Floyd et al. 2010) set under the International Standards for Phytosanitary Measures (ISPM) No. 27, ''Diagnostic Protocols for Regulated Pests'' and has been validated for use in regulatory sciences (Jones et al. 2013), it is positioned for adoption as the preferred diagnostic tool for species for quarantine and regulation. For example, USDA-Agriculture Research Service is using DNA barcodes to monitor pest and invasive arthropods (http://agresearchmag.ars.usda.gov/AR/archive/2012/Apr/insects0412.pdf). However, the incorporation of this technology into the routine workflows of regulatory agencies is still under development. There is a particular need to develop well-parameterized reference datasets on important pest species for the countries of origin. Because nearly 75% of all BINs on BOLD, in general, derive from North America and Europe, with relatively low coverage for regions that host many potentially important global pests, there is a need for aggressive efforts for further parameterization of the barcode reference library. However, even before this task is complete, DNA barcode analysis makes it possible to signal the detection of any newly encountered species, providing a stimulus for its further investigation.

Conclusions

The increased global trade in plants and plant products has dramatically increased the risk of introducing novel pest species, creating the potential for massive economic losses to agriculture and forestry. For example, loss linked to the introduction of the emerald ash borer into North America has been estimated at tens of billions of dollars (Kovacs et al 2010, Herms and McCullough 2014). Because of its capability to support large-scale bio-surveillance programs, DNA barcoding can be an effective tool for intercepting invasive species at their points of introduction, and can also enable their early detection in natural environments. While species-specific primer sets can be a valuable tool for the quarantine detection of a particular species (Yeh et al. 2014), there is a critical need to gain a deeper understanding of diversity in many pest species as nearly one third of these taxa on BOLD (Table 1) appear to represent a species complex. High throughput sequencing platforms represent a powerful technology which will enable the use of DNA barcoding in large-scale bio-surveillance programs which can target both known pest species and new arrivals (Pochon et al. 2013). Given the complexities in morphological discrimination of many cryptic taxa, there is an obvious need to adopt DNA-based systems of nomenclature for pest regulation and quarantine (Cook et al. 2010).

References

Abd-Rabou, S., Shalaby, H., Germain, J.F., Ris, N., Kreiter, P., and Malausa, T. 2012. Identification of mealybug pest species (Hemiptera: Pseudococcidae) in Egypt and France, using a DNA barcoding approach. Bull. Entomol. Res. **102**(5): 515-523.

Adrion, J.R., Kousathanas, A., Pascual, M., Burrack, H.J., Haddad, N.M., Bergland, A.O., et al. 2014. *Drosophila suzukii*: The genetic footprint of a recent, worldwide invasion. Mol. Biol. Evol. **31**(12): 3148-3163.

Amin, S., Scheffer, S.J., Lewis, M.L., Pasha, M.K., and Bhuiya, B.A. 2014. DNA barcoding of the vegetable leafminer *Liriomyza sativae* Blanchard (Diptera: Agromyzidae) in Bangladesh. DNA Barcodes **2**(1): 29-33.

Armstrong, K.F. 2010. DNA barcoding: a new module in New Zealand's plant biosecurity diagnostic toolbox. EPPO Bull. **40**(1): 91-100.

Armstrong, K.F., and Ball, S.L. 2005. DNA barcodes for biosecurity: invasive species identification. Phil. Trans. R. Soc. Lond. B Biol. Sci. **360**(1462): 1813-1823.

Ascunce, M.S., Ernst, J.A., Clark, A., and Nigg, H.N. 2008. Mitochondrial nucleotide variability in invasive populations of the root weevil *Diaprepes abbreviatus* (Coleoptera: Curculionidae) of Florida and preliminary assessment of *Diaprepes* sp. from Dominica. J. Econ. Entomol. **101**(4): 1443-1454.

Ashfaq, M., Akhtar, S., Khan, A.M., Adamowicz, S.J., and Hebert, P.D.N. 2013. DNA barcode analysis of butterfly species from Pakistan points towards regional endemism. Mol. Ecol. Resour. **13**(5): 832-843.

Ashfaq, M., Ara, J., Noor, A.R., Hebert, P.D.N., and Mansoor, S. 2011. Molecular phylogenetic analysis of a scale insect (*Drosicha mangiferae*; Hemiptera: Monophlebidae) infesting mango orchards in Pakistan. Eur. J. Entomol. **108**(4): 553-559.

Ashfaq, M., Hebert, P.D.N., Mirza, M.S., Khan, A.M., Mansoor, S., Shah, G.S., et al. 2014. DNA barcoding of *Bemisia tabaci* complex (Hemiptera: Aleyrodidae) reveals southerly expansion of the dominant whitefly species on cotton in Pakistan. PLOS ONE **9**(8): e104485.

Ashfaq, M., Prosser, S., Nasir, S., Masood, M., Ratnasingham, S., and Hebert, P.D.N. 2015. High diversity and rapid diversification in the head louse, *Pediculus humanus* (Pediculidae: Phthiraptera). Sci. Rep. **5**: 14188. doi: 10.1038/srep14188.

Aukema, J.E., Leung, B., Kovacs, K., Chivers, C., Britton, K.O., Englin, J., et al. 2011. Economic impacts of non-native forest insects in the continental United States. PLOS ONE **6**(9): e24587.

Ball, S.L., and Armstrong, K.F. 2006. DNA barcodes for insect pest identification: a test case with tussock moths (Lepidoptera: Lymantriidae). Can. J. Forest Res. **36**(2): 337-350.

Bellis, G.A., Gopurenko, D., Cookson, B., Postle, A.C., Halling, L., Harris, N., et al. 2015. Identification of incursions of *Culicoides* Latreille species (Diptera: Ceratopogonidae) in Australasia using morphological techniques and DNA barcoding. Austral. Entomol. **54**(3): 332-338.

Bernardo, U., van Nieukerken, E.J., Sasso, R., Gebiola, M., Gualtieri, L., and Viggiani, G. 2015. Characterization, distribution, biology and impact on Italian walnut orchards of the invasive North-American leafminer *Coptodisca lucifluella* (Lepidoptera: Heliozelidae). Bull. Entomol. Res. **105**(2): 210-224.

Bergsten, J., Bilton, D.T., Fujisawa, T., Elliott, M., Monaghan, M.T., Balke, M., et al. 2012. The effect of geographical scale of sampling on DNA barcoding. Syst. Biol. **61**(5): 851-869.

Blacket, M.J., Rice, A.D., Semeraro, L., and Malipatil, M.B. 2015. DNA-based identifications reveal multiple introductions of the vegetable leafminer *Liriomyza sativae* (Diptera: Agromyzidae) into the Torres Strait Islands and Papua New Guinea. Bull. Entomol. Res. **105**(5): 533-544.

Blagoev, G.A., deWaard, J.R., Ratnasingham, S., deWaard, S.L., Lu, L., Robertson, J., et al. 2015. Untangling taxonomy: a DNA barcode reference library for Canadian spiders. Mol. Ecol. Resour. **16**(1): 325-341.

Blaxter, M., Mann, J., Chapman, T., Thomas, F., Whitton, C., Floyd, R., et al. 2005. Defining operational taxonomic units using DNA barcode data. Phil. Trans. R. Soc. B: Biol. Sci. **360**(1462): 1935-1943.

Burns, J.M., Janzen, D.H., Hajibabaei, M., Hallwachs, W., and Hebert, P.D.N. 2008. DNA barcodes and cryptic species of skipper butterflies in the genus *Perichares* in Area de Conservacion Guanacaste, Costa Rica. Proc. Natl. Acad. Sci. USA **105**(17): 6350-6355.

Candek, K., and Kuntner, M. 2015. DNA barcoding gap: reliable species identification over morphological and geographical scales. Mol. Ecol. Resour. **15**: 268-277.

Cesari, M., Maistrello, L., Ganzerli, F., Dioli, P., Rebecchi, L., and Guidetti, R. 2015. A pest alien invasion in progress: potential pathways of origin of the brown marmorated stink bug *Halyomorpha halys* populations in Italy. J. Pest Sci. **88**(1): 1-7.

Chang, H., Liu, Q., Hao, D., Liu, Y., An, Y., Qian, L., and Yang, X. 2014. DNA barcodes and molecular diagnostics for distinguishing introduced *Xyleborus* (Coleoptera: Scolytinae) species in China. Mitochondr. DNA **25**(1): 63-69.

Chowda-Reddy, R.V., Kirankumar, M., Seal, S.E., Muniyappa, V., Valand, G.B., Govindappa, M.R., et al. 2012. *Bemisia tabaci* phylogenetic groups in India and the relative transmission efficacy of *Tomato leaf curl Bangalore virus* by an indigenous and an exotic population. J. Integr. Agric. **11**(2): 235-248.

Chown, S., Sinclair, B., and van Vuuren, B. 2008. DNA barcoding and the documentation of alien species establishment on sub-Antarctic Marion Island. Polar Biol. **31**(5): 651-655.

Cook, L.G., Edwards, R.D., Crisp, M.D., and Hardy, N.B. 2010. Need morphology always be required for new species descriptions? Invertebr. Syst. **24**(3): 322-326.

Davis, G.A., Havill, N.P., Adelman, Z.N., Caccone, A., Kok, L.T., and Salom, S.M. 2011. DNA barcodes and molecular diagnostics to distinguish an introduced and native *Laricobius* (Coleoptera: Derodontidae) species in eastern North America. Biol. Control **58**(1): 53-59.

De Barro, P., and Ahmed, M.Z. 2011. Genetic networking of the *Bemisia tabaci* cryptic species complex reveals pattern of biological invasions. PLOS ONE **6**(10): e25579.

Derocles, S.A., Evans, D.M., Nichols, P.C., Evans, S.A., and Lunt, D.H. 2015. Determining plant - leafminer - parasitoid interactions: a DNA barcoding approach. PLOS ONE **10**(2): e0117872.

deWaard, J.R., Mitchell, A., Keena, M.A., Gopurenko, D., Boykin, L.M., Armstrong, K.F., et al. 2010. Towards a global barcode library for *Lymantria* (Lepidoptera: Lymantriinae) tussock moths of biosecurity concern. PLOS ONE **5**(12): e14280.

Dickey, A.M., Kumar, V., Hoddle, M.S., Funderburk, J.E., Morgan, J.K., Jara-Cavieres, A., et al. 2015. The *Scirtothrips dorsalis* species complex: endemism and invasion in a global pest. PLOS ONE **10**(4): e0123747.

Dinca, V., Montagud, S., Talavera, G., Hernandez-Roldan, J., Munguira, M.L., Garcia-Barros, E., et al. 2015. DNA barcode reference library for Iberian butterflies enables a continental-scale preview of potential cryptic diversity. Sci. Rep. **5:** 12395. doi:10.1038/srep12395.

Dong, C., Guo-Xia, L., Hai-Bin, F., and Wei, X. 2009. Phylogenetic analysis of mtCOI reveals the cryptic lineages in *Phenacoccus solenopsis* complex (Hemiptera: Pseudococcidae). Acta Entomol. Sinica **52**(1): 1261-1265.

Dumas, P., Barbut, J., Le Ru, B., Silvain, J-F., Clamens, A-L., d'Alencon, E., et al. 2015. Phylogenetic molecular delimitations unravel potential new species in the pest genus *Spodoptera* Guenee, 1852 (Lepidoptera, Noctuidae). PLOS ONE **10**(4): 0122407.

Ekrem, T., Willassen, E., and Stur, E. 2007. A comprehensive DNA sequence library is essential for identification with DNA barcodes. Mol. Phylogenet. Evol. **43**(2): 530-542.

Erlandson, M., Braun, L., Baldwin, D., Soroka, J., Ashfaq, M., and Hegedus, D. 2003. Molecular markers for *Peristenus spp*. (Hymenoptera : Braconidae) parasitoids associated with *Lygus* spp. (Hemiptera : Miridae). Can. Entomol. **135**(1): 71-83.

Etzler, F.E., Wanner, K.W., Morales-Rodriguez, A., and Ivie, M.A. 2014. DNA barcoding to improve the species-level management of wireworms (Coleoptera: Elateridae). J. Econ. Entomol. **107**(4): 1476-1485.

Floyd, R., Lima, J., deWaard, J., Humble, L., and Hanner, R. 2010. Common goals: policy implications of DNA barcoding as a protocol for identification of arthropod pests. Biol. Invasions **12**: 2947–2954.

Foottit, R.G., Maw, E., and Hebert, P.D.N. 2014. DNA barcodes for Nearctic Auchenorrhyncha (Insecta: Hemiptera). PLOS ONE **9**(7): e101385.

Foottit, R.G., Maw, H.E.L., Von Dohlen, C.D., and Hebert, P.D.N. 2008. Species identification of aphids (Insecta: Hemiptera: Aphididae) through DNA barcodes. Mol. Ecol. Resour. **8**(6): 1189-1201.

Frewin, A.J., Scott-Dupree, C., and Hanner, R. 2013. DNA barcoding for plant protection: Applications and summary of available data for arthropod pests. CAB Reviews **8**: 1-13.

Frewin, A.J., Scott-Dupree, C., Murphy, G., and Hanner, R. 2014. Demographic trends in mixed *Bemisia tabaci* (Hemiptera: Aleyrodidae) cryptic species populations in commercial poinsettia under biological control- and insecticide-based management. J. Econ. Entomol. **107**(3): 1150-1155.

Frey, J.E., Guillen, L., Frey, B., Samietz, J., Rull, J., and Aluja, M. 2013. Developing diagnostic SNP panels for the identification of true fruit flies (Diptera: Tephritidae) within the limits of COI-based species delimitation. BMC Evol. Biol. **13**: 1-19.

Fujisawa, T., and Barraclough, T.G. 2013. Delimiting species using single-locus data and the Generalized Mixed Yule Coalescent approach: A revised method and evaluation on simulated data sets. Syst. Biol. **62**(5):707-724.

Gauthier, N. 2010. Multiple cryptic genetic units in *Hypothenemus hampei* (Coleoptera: Scolytinae): evidence from microsatellite and mitochondrial DNA sequence data. Biol. J. Linn. Soc. **101**(1): 113-129.

Gul, H., Bajwa, G.A., and Panhwar, G.N. 1997. Integrated control of mango mealy bug *Drosicha stebbingi* green (Hemiptera: Margarodidae) infesting forestry tree species at the Pakistan Forest Institute, Peshawar. Pak. J. Forestry **47**: 65-72.

Gwiazdowski, R.A., Foottit, R.G., Maw, H.E.L., and Hebert, P.D.N. 2015. The Hemiptera (Insecta) of Canada: constructing a reference library of DNA barcodes. PLOS ONE **10**(4): e0125635.

Harrison, R.G., and Larson, E.L. 2014. Hybridization, introgression, and the nature of species boundaries. J. Hered. **105** (S1): 795-809.

Hausmann, A., Godfray, H.C., Huemer, P., Mutanen, M., Rougerie, R., van Nieukerken, E.J., et al. 2013. Genetic patterns in European geometrid moths revealed by the Barcode Index Number (BIN) system. PLOS ONE **8**(12): e84518.

Hebert, P.D.N., Cywinska, A., Ball, S.L., and deWaard, J.R. 2003*a*. Biological identifications through DNA barcodes. Proc. R. Soc. B **270**(1512): 313-321.

Hebert, P.D.N., Ratnasingham, S., and deWaard, J.R. 2003*b*. Barcoding animal life: cytochrome *c* oxidase subunit 1 divergences among closely related species. Proc. Biol. Sci. **270** Suppl 1: S96-99.

Hendrich, L., Moriniere, J., Haszprunar, G., Hebert, P.D.N., Hausmann, A., Kohler, F., et al. 2015. A comprehensive DNA barcode database for Central European beetles with a focus on Germany: adding more than 3500 identified species to BOLD. Mol. Ecol. Resour. **15**(3): 795-818.

Hendrichs, J., Vera, M.T., Meyer, M.D., and Clarke, A.R. 2015. Resolving cryptic species complexes of major tephritid pests. ZooKeys **540**: 5-39.

Herms, D.A., and McCullough, D.G. 2014. Emerald ash borer invasion of North America: History, biology, ecology, impacts, and management. Annu. Rev. Entomol. **59**: 13-30.

Hinomoto, N., Tran, D.P., Pham, A.T., Le, T.B.N., Tajima, R., Ohashi, K., et al. 2007. Identification of spider mites (Acari: Tetranychidae) by DNA sequences: A case study in northern Vietnam. Int. J. Acarol. **33**(1): 53-60.

Huemer, P., Karsholt, O., and Mutanen, M. 2014*a*. DNA barcoding as a screening tool for cryptic diversity: an example from *Caryocolum*, with description of a new species (Lepidoptera, Gelechiidae). ZooKeys **404**: 91-111.

Huemer, P., Mutanen, M., Sefc, K.M., and Hebert, P.D.N. 2014*b*. Testing DNA barcode performance in 1000 species of European Lepidoptera: large geographic distances have small genetic impacts. PLOS ONE **9**(12): e115774.

Humphries, E.M., and Winker, K. 2011. Discord reigns among nuclear, mitochondrial and phenotypic estimates of divergence in nine lineages of trans-Beringian birds. Mol. Ecol. **20**: 573-583.

Iftikhar, R., Ashfaq, M., Rasool, A., and Hebert, P.D.N. 2016. DNA barcode analysis of thrips (Thysanoptera) diversity in Pakistan reveals cryptic species complexes. PLOS ONE **11**(1): e0146014.

Jacobson, A.L., Booth, W., Vargo, E.L., and Kennedy, G.G. 2013. *Thrips tabaci* population genetic structure and polyploidy in relation to competency as a vector of *Tomato spotted wilt virus*. PLOS ONE **8**(1): e54484.

Janzen, D.H., Hajibabaei, M., Burns, J.M., Hallwachs, W., Remigio, E., and Hebert, P.D.N. 2005. Wedding biodiversity inventory of a large and complex Lepidoptera fauna with DNA barcoding. Phil. Trans. R. Soc. Lond. B Biol. Sci. **360**(1462): 1835-1845.

Jendek, E., Grebennikov, V.V., and Bocak, L. 2015. Undetected for a century: Palaearctic *Agrilus ribesi* Schaefer (Coleoptera: Buprestidae) on currant in North America, with adult morphology, larval biology and DNA barcode. Zootaxa **4034**(1): 112-126.

Jiang, F., Jin, Q., Liang, L., Zhang, A.B., and Li, Z.H. 2014. Existence of species complex largely reduced barcoding success for invasive species of Tephritidae: a case study in *Bactrocera* spp. Mol. Ecol. Resour. **14**(6): 1114-1128.

Jiang-Ling, Y., Yu-Lin, A.N., Lu, Q., Xiao-Jun, Y., Mei, X., Cui-Ping, W., et al. 2015. Development and application of quarantine insect DNA barcoding technology. Chinese J. Appl. Entomol. **52**(2): 382-389.

Johnson, A.J., Weintraub, P.G., Katoch, R., Schemerhorn, B.J., and Shukle, R.H. 2012. Biological and molecular characterization of Hessian fly (Diptera: Cecidomyiidae) from Israel. Bull. Entomol. Res. **102**(6): 632-643.

Jones, Y.L., Peters, S.M., Weland, C., Ivanova, N.V., and Yancy, H.F. 2013. Potential use of DNA barcodes in regulatory science: Identification of the U.S. Food and Drug Administration's "Dirty 22," contributors to the spread of foodborne pathogens. J. Food Prot. **76**(1): 144-149.

Jordal, B.H., and Kambestad, M. 2014. DNA barcoding of bark and ambrosia beetles reveals excessive NUMTs and consistent east-west divergence across Palearctic forests. Mol. Ecol. Resour. **14**(1): 7-17.

Jörger, K.M., Norenburg, J.L., Wilson, N.G., and Schrödl, M. 2012. Barcoding against a paradox? Combined molecular species delineations reveal multiple cryptic lineages in elusive meiofaunal sea slugs. BMC Evol. Biol. **12**: 245. DOI: 10.1186/1471-2148-12-245.

Jörger, K.M., and Schrödl, M. 2013. How to describe a cryptic species? Practical challenges of molecular taxonomy. Front. Zool. **10**(10.1186): 1742-9994.

Kadirvel, P., Srinivasan, R., Hsu, Y.-C., Su, F.-C., and de la Pena, R. 2013. Application of cytochrome oxidase I sequences for phylogenetic analysis and identification of thrips species occurring on vegetable crops. J. Econ. Entomol. **106**(1): 408-418.

Kang, T.H., Lee, K.-S., and Lee, H.-S. 2015. DNA barcoding of the Korean *Lymantria* Hubner, 1819 (Lepidoptera: Erebidae: Lymantriinae) for quarantine inspection. J. Econ. Entomol. **108**(4): 1596-1611.

Kekkonen, M., and Hebert, P.D.N. 2014. DNA barcode-based delineation of putative species: efficient start for taxonomic workflows. Mol. Ecol. Resour. **14**(4): 706-715.

Kekkonen, M., Mutanen, M., Kaila, L., Nieminen, M., and Hebert, P.D.N. 2015. Delineating species with DNA barcodes: A case of taxon dependent method performance in moths. PLOS ONE **10**(4): e0122481.

Khamis, F.M., Masiga, D.K., Mohamed, S.A., Salifu, D., de Meyer, M., and Ekesi, S. 2012. Taxonomic identity of the invasive fruit fly pest, *Bactrocera invadens*: concordance in morphometry and DNA barcoding. PLOS ONE **7**(9): e44862.

Kovacs, K.F., Haight, R.G., McCullough D.G., Mercader R.J., Siegert N.W., and Liebhold, A.M. 2010. Cost of potential emerald ash borer damage in U.S. communities 2009-2019. Ecol. Econ. **69**: 569-578.

Lammers, Y., Peelen, T., Vos, R.A., and Gravendeel, B. 2014. The HTS barcode checker pipeline, a tool for automated detection of illegally traded species from high-throughput sequencing data. BMC Bioinformatics **15**: 44. doi:10.1186/1471-2105-15-44.

Latif, A. 1949. The taxonomic status of *Drosicha stebbingi* (Green) and *Drosicha mangiferae* (Green) (Hem., Coccid.). Bull. Entomol. Res. **40**(3): 351-354.

Lee, W., Park, J., Lee, G.-S., Lee, S., and Akimoto, S.-I. 2013. Taxonomic status of the *Bemisia tabaci* complex (Hemiptera: Aleyrodidae) and reassessment of the number of its constituent species. PLOS ONE **8**(5): e63817.

Li, Q.Q., Li, D.Y., Ye, H., Liu, X.F., Shi, W., Cao, N., and Duan, Y.Q. 2011. Using COI gene sequence to barcode two morphologically alike species: the cotton bollworm and the oriental tobacco budworm (Lepidoptera: Noctuidae). Mol. Biol. Rep. **38**(8): 5107-5113.

Li, Y., Duan, X., Qiao, X., Li, X., Wang, K., Men, Q., et al. 2015. Mitochondrial DNA revealed the extent of genetic diversity and invasion origin of populations from two separate invaded areas of a newly invasive pest, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) in China. Bull. Entomol. Res. **105**(4): 485-496.

Liebhold, A.M., McCullough, D.G., Blackburn, L.M., Frankel, S.J., Von Holle, B., and Aukema, J.E. 2013. A highly aggregated geographical distribution of forest pest invasions in the USA. Divers. Distrib. **19**(9): 1208-1216.

Lukhtanov, V.A., Sourakov, A., Zakharov EV., and Hebert, P.D.N. 2009. DNA barcoding Central Asian butterflies: Increasing geographical dimension does not significantly reduce the success of species identification. Mol. Ecol. Resour. **9**(5): 1302-1310.

MacLeod, N., Benfield, M., and Culverhouse, P. 2010. Time to automate identification. Nature **467**(7312): 154-155. doi: 10.1038/467154a.

Mally, R., Korycinska, A., Agassiz D.J.L., Hall, J., Hodgetts, J., and Nuss, M. 2015. Discovery of an unknown diversity of *Leucinodes* species damaging Solanaceae fruits in sub-Saharan Africa and moving in trade (Insecta, Lepidoptera, Pyraloidea). ZooKeys **472**: 117-162.

Matsuda, T., Fukumoto, C., Hinomoto, N., and Gotoh, T. 2013. DNA-based identification of spider mites: molecular evidence for cryptic species of the genus *Tetranychus* (Acari: Tetranychidae). J. Econ. Entomol. **106**(1): 463-472.

Mastrangelo, T., Paulo, D.F., Bergamo, L.W., Morais, E.G.F., Silva, M., Bezerra-Silva, G., et al. 2014. Detection and genetic diversity of a Heliothine invader (Lepidoptera: Noctuidae) from north and northeast of Brazil. J. Econ. Entomol. **107**(3): 970-980.

Mathur, S., Cook, M.A., Sinclair, B.J., and Fitzpatrick, S.M. 2012. DNA barcodes suggest cryptic speciation in *Dasineura oxycoccana* (Diptera: Cecidomyiidae) on cranberry, *Vaccinium macrocarpon*, and blueberry, *V. corymbosum*. Fla. Entomol. **95**(2): 387-394.

Mrinalini, Thorpe, R.S., Creer, S., Lallias, D., Dawnay, L., Stuart, B.L., Malhotra, A. 2015. Convergence of multiple markers and analysis methods defines the genetic distinctiveness of cryptic pitvipers. Mol. Phylogenet. Evol. **92**: 266-279.

Mutanen, M., Hausmann, A., Hebert, P.D.N., Landry, J.F., de Waard, J.R., and Huemer, P. 2012. Allopatry as a gordian knot for taxonomists: patterns of DNA barcode divergence in arctic-alpine Lepidoptera. PLOS ONE **7**(10): e47214.

Mutanen, M., Kaila, L., and Tabell, J. 2013. Wide-ranging barcoding aids discovery of one-third increase of species richness in presumably well-investigated moths. Sci. Rep. **3:** 2901. doi:10.1038/srep02901

Mutanen, M., Kekkonen, M., Prosser, S.W.J., Hebert, P.D.N., and Kaila, L. 2015. One species in eight: DNA barcodes from type specimens resolve a taxonomic quagmire. Mol. Ecol. Resour. **15**(4): 967-984.

Nadel, R.L., Slippers, B., Scholes, M.C., Lawson, S.A., Noack, A.E., Wilcken, C.F., et al. 2010. DNA bar-coding reveals source and patterns of *Thaumastocoris peregrinus* invasions in South Africa and South America. Biol. Invasions **12**(5): 1067-1077.

Nagoshi, R.N., Brambila, J., and Meagher, R.L. 2011. Use of DNA barcodes to identify invasive armyworm *Spodoptera* species in Florida. J. Insect Sci. **11**(154): doi: 10./031.011.

Nagoshi, R.N., Paraiso, O., Brambila, J., and Kairo, M.T. 2012. Assessing the usefulness of DNA barcoding to identify *Oxycarenus hyalinipennis* (Hemiptera: Oxycarenidae) in Florida, a potentially invasive pest of cotton. Fla. Entomol. **95**(4): 1174-1181.

Nagy, Z.T., Sonet, G., Mortelmans, J., Vandewynkel, C., and Grootaert, P. 2013. Using DNA barcodes for assessing diversity in the family Hybotidae (Diptera, Empidoidea). ZooKeys **365**: 263-278.

Onah, I.E., Eyo, J.E., and Taylor, D. 2015. Molecular identification of tephritid fruit flies (Diptera: Tephritidae) infesting sweet oranges in Nsukka Agro-Ecological Zone, Nigeria, based on PCR-RFLP of COI gene and DNA barcoding. Afr. Entomol. **23**(2): 342-347.

Ovalle, T.M., Parsa, S., Hernandez, M.P., and Becerra Lopez-Lavalle, L.A. 2014. Reliable molecular identification of nine tropical whitefly species. Ecol. Evol. **4**(19): 3778-3787.

Park, D.-S., Suh, S.-J., Hebert, P.D.N., Oh, H.-W., and Hong, K.-J. 2011*a*. DNA barcodes for two scale insect families, mealybugs (Hemiptera: Pseudococcidae) and armored scales (Hemiptera: Diaspididae). Bull. Entomol. Res. **101**(04): 429-434.

Park, D.S., Foottit, R., Maw, E., and Hebert, P.D.N. 2011*b*. Barcoding bugs: DNA-based identification of the true bugs (Insecta: Hemiptera: Heteroptera). PLOS ONE **6**(4): e18749.

Pentinsaari, M., Hebert, P.D.N., and Mutanen, M. 2014. Barcoding beetles: a regional survey of 1872 species reveals high identification success and unusually deep interspecific divergences. PLOS ONE **9**(9): 2014.

Piffaretti, J., Rossi, J.P., Vanlerberghe-Masutti, F., Genson, G., Coeur d'Acier, A., and Jousselin, E. 2013. Molecular identification and ecological characteristics of two cryptic lineages within a cosmopolitan aphid pest, *Brachycaudus helichrysi* (Hemiptera: Aphididae). Appl. Entomol. Zool. **48**(2): 155-164.

Pochon, X., Bott, N.J,, Smith, K.F., and Wood, S.A. 2013. Evaluating detection limits of next-generation sequencing for the surveillance and monitoring of international marine pests. PLOS ONE **8**(9): e73935.

Pons, J., Barraclough, T.G., Gomez-Zurita, J., Cardoso1, A., Duran1, D.P., Hazell, S., et al. 2006. Sequence-based species delimitation for the DNA taxonomy of undescribed insects. Syst. Biol. **55**(4): 595-609.

Puillandre, N., Lambert, A., Brouillet, S., and Achaz, G. 2012. ABGD, Automatic Barcode Gap Discovery for primary species delimitation. Mol. Ecol. **21**(8): 1864-1877.

Qiao, W.-N., Wan, F.-H., Zhang, A.-B., Min, L., and Zhang, G.-F. 2012. Application of DNA barcoding technology for species identification of common thrips (Insecta: Thysanoptera) in China. Acta Entomol. Sinica **55**(3): 344-356.

Rakauskas, R., and Basilova, J. 2013. Barcoding of aphids (Hemiptera, Aphididae and Adelgidae): Proper usage of the global data set. Mol. Ecol. Resour. **13**(1): 6-9.

Ratnasingham, S., and Hebert, P.D.N. 2007. BOLD: The Barcode of Life Data System (http://www.barcodinglife.org). Mol. Ecol. Notes **7**(3): 355-364.

Ratnasingham, S., and Hebert, P.D.N. 2013. A DNA-based registry for all animal species: The Barcode Index Number (BIN) system. PLOS ONE **8**(7): e66213.

Raupach, M.J., Hendrich, L., Kuchler, S.M., Deister, F., Moriniere, J., and Gossner, M.M. 2014. Building-up of a DNA barcode library for true bugs (Insecta: Hemiptera: Heteroptera) of Germany reveals taxonomic uncertainties and surprises. PLOS ONE **9**(9): e106940.

Rebijith, K.B., Asokan, R., Kumar, N.K., Krishna, V., Chaitanya, B.N., and Ramamurthy, V.V. 2013. DNA barcoding and elucidation of cryptic aphid species (Hemiptera: Aphididae) in India. Bull. Entomol. Res. **103**(5): 601-610.

Rebijith, K.B., Asokan, R., Krishna, V., Ranjitha, H.H., Kumar, N.K.K., and Ramamurthy, V.V. 2014. DNA barcoding and elucidation of cryptic diversity in thrips (Thysanoptera). Fla. Entomol. **97**(4): 1328-1347.

Rivera, J., and Currie, D.C. 2009. Identification of Nearctic black flies using DNA barcodes (Diptera: Simuliidae). Mol. Ecol. Resour. **9**: 224-236.

Robe, L.J., De Re, F.C., Ludwig, A., and Loreto, E.L. 2013. The *Drosophila flavopilosa* species group (Diptera, Drosophilidae): an array of exciting questions. Fly **7**(2): 59-69.

Roderick, G.K., Hufbauer, R., and Navajas, M. 2012. Evolution and biological control. Evol. Appl. **5**(5): 419–423.

Ros, V.I.D., and Breeuwer, J.A.J. 2007. Spider mite (Acari: Tetranychidae) mitochondrial COI phylogeny reviewed: host plant relationships, phylogeography, reproductive parasites and barcoding. Exp. Appl. Acarol. **42**: 239-262.

Rougerie, R., Kitching, I.J., Haxaire, J., Miller, S.E., Hausmann, A., and Hebert, P.D.N. 2014. Australian Sphingidae - DNA barcodes challenge current species boundaries and distributions. PLOS ONE **9**(7): e101108.

Rougerie, R., Lopez-Vaamonde, C., Barnouin, T., Delnatte, J., Moulin, N., Noblecourt, T., et al. 2015. PASSIFOR: A reference library of DNA barcodes for French saproxylic beetles (Insecta, Coleoptera). Biodivers. Data J. **4**(3): e4078.

Rugman-Jones, P.F., Hoddle, M.S., and Stouthamer, R. 2010. Nuclear-mitochondrial barcoding exposes the global pest Western flower thrips (Thysanoptera: Thripidae) as two sympatric cryptic species in its native California. J. Econ. Entomol. **103**(3): 877-886.

Saitou, N., and Nei, M. 1987. The Neighbor-Joining method: a new method for reconstructing phylogenetic trees. Mol. Biol. Evol. **4**(4): 406-425.

Savolainen, V., Cowan, R.S., Vogler, A.P., Roderick, G.K., and Lane, R. 2005. Towards writing the encyclopaedia of life: An introduction to DNA barcoding. Phil. Trans. R. Soc. B **360**: 1805-1811.

Scheffer, S.J., Lewis, M.L., Gaimari, S.D., and Reitz, S.R. 2014. Molecular survey for the invasive leafminer pest *Liriomyza huidobrensis* (Diptera: Agromyzidae) in California uncovers only the native pest *Liriomyza langei*. J. Econ. Entomol. **107**(5): 1959-1964.

Schloss, P.D., and Handelsman, J. 2005. Introducing DOTUR, a computer program for defining operational taxonomic units and estimating species richness. Appl. Environ. Microb. **71**(3): 1501-1506.

Schutze, M.K., Krosch, M.N., Armstrong, K.F., Chapman, T.A., Englezou, A., ChomiÄ , A., et al. 2012. Population structure of *Bactrocera dorsalis* s.s., *B. papayae* and *B. philippinensis* (Diptera: Tephritidae) in Southeast Asia: evidence for a single species hypothesis using mitochondrial DNA and wing-shape data. BMC Evol. Biol. **12**(1): 130.

Schutze, M.K., Aketarawong, N., Amornsak, W., Armstrong, K.F., Augustinos, A.A., Barr, N., et al. 2015. Synonymization of key pest species within the *Bactrocera dorsalis* species complex (Diptera: Tephritidae): taxonomic changes based on a review of 20 years of integrative morphological, molecular, cytogenetic, behavioural and chemoecological data. Syst. Entomol. **40**: 456-471.

Shashank, P., Chakravarthy, A., Raju, B., and Bhanu, K. 2014. DNA barcoding reveals the occurrence of cryptic species in host-associated population of *Conogethes punctiferalis* (Lepidoptera: Crambidae). Appl. Entomol. Zool. **49**(2): 283-295.

Shin, S., Jung, S., Heller, K., Menzel, F., Hong, T.K., Shin, J.S., et al. 2015. DNA barcoding of *Bradysia* (Diptera: Sciaridae) for detection of the immature stages on agricultural crops. J. Appl. Entomol. **139**(8): 638-645.

Shin, S., Jung, S., Lee, H., and Lee, S. 2013. Molecular identification of dipteran pests (Diptera: Sciaroidea) from shiitake mushroom. Mol. Ecol. Resour. **13**(2): 200-209.

Shokralla, S., Gibson, J.F., Nikbakht, H., Janzen, D.H., Hallwachs, W., and Hajibabaei, M. 2014. Next-generation DNA barcoding: using next-generation sequencing to enhance and accelerate DNA barcode capture from single specimens. Mol. Ecol. Resour. **14**(5): 892-901.

Simmons, R.B., and Scheffer, S.J. 2004. Evidence of cryptic species within the pest *Copitarsia decolora* (Guenee) (Lepidoptera: Noctuidae). Ann. Entomol. Soc. Am. **97**(4): 675-680.

Smit, J., Reijnen, B., and Stokvis, F. 2013. Half of the European fruit fly species barcoded (Diptera, Tephritidae); a feasibility test for molecular identification. ZooKeys **365**: 279-305.

Stahlhut, J.K., Fernandez-Triana, J., Adamowicz, S.J., Buck, M., Goulet, H., Hebert, P.D.N., et al. 2013. DNA barcoding reveals diversity of Hymenoptera and the dominance of parasitoids in a sub-arctic environment. BMC Ecol. **13**(2): 1472-6785.

Sumalde, A.A.M., Mendioro, M.S., Delomen, M.L.C., and Medina, C.D. 2013. DNA barcoding and morphometric analyses of oriental fruit fly species *Bactrocera occipitalis* (Bezzi) and *B. philippinensis* (Drew and Hancock) (Diptera: Tephritidae) from Guimaras, Philippines. Philipp. Entomol. **27**(1): 58-74.

Taberlet, P., Coissac, E., Pompanon, F., Brochmann, C., and Willerslev, E. 2012. Towards next-generation biodiversity assessment using DNA metabarcoding. Mol. Ecol. **21**(8): 2045-2050.

Takano, S.-I., Mochizuki, A., Konishi, K., Takasu, K., Alouw, J.C., Pandin, D.S., et al. 2011. Two cryptic species in *Brontispa longissima* (Coleoptera: Chrysomelidae): Evidence from mitochondrial DNA analysis and crosses between the two nominal species. Ann. Entomol. Soc. Am. **104**(2): 121-131.

Tedersoo, L., Ramirez, K.S., Nilsson, R.H., Kaljuvee, A., Koljalg, U., and Abarenkov, K. 2015. Standardizing metadata and taxonomic identification in metabarcoding studies. GigaScience 4: 34-34.

Telfer, A.C., Young, M.R., Quinn, J., Peraz, K., Sobel, C.N., Sones, J.E., et al. 2015. Biodiversity inventories in high gear: DNA barcoding facilitates a rapid biotic survey of a temperate nature reserve. Biodiv. Data J. **3**: e6313.

ToŠEvski, I.V.O., Caldara, R., JoviĆ, J., HernÁNdez-Vera, G., Baviera, C., Gassmann, A., et al. 2011. Morphological, molecular and biological evidence reveal two cryptic species in *Mecinus janthinus* Germar (Coleoptera, Curculionidae), a successful biological control agent of Dalmatian toadflax, *Linaria dalmatica* (Lamiales, Plantaginaceae). Syst. Entomol. **36**(4): 741-753.

Tyagi, K., Kumar, V., Singha, D., and Chakraborty, R. 2015. Morphological and DNA barcoding evidence for invasive pest thrips, *Thrips parvispinus* (Thripidae: Thysanoptera), newly recorded from India. J. Insect Sci. **15**(105). doi: 10.1093/jisesa/iev087.

Unterseher, M., Jumpponen, A., Oepik, M., Tedersoo, L., Moora, M., Dormann, C.F., et al. 2011. Species abundance distributions and richness estimations in fungal metagenomics - lessons learned from community ecology. Mol. Ecol. **20**(2): 275-285.

van de Vossenberg, B.T.L.H., Westenberg, M., and Bonants, P.J.M. 2013. DNA barcoding as an identification tool for selected EU-regulated plant pests: an international collaborative test performance study among 14 laboratories. EPPO Bull. **43**(2): 216-228.

Van Lenteren, J.C., Babendreier, D., Bigler, F., Burgio, G., Hokkanen, H.M.T., Kuske, S., et al. 2003. Environmental risk assessment of exotic natural enemies used in inundative biological control. Bio Control **48**(1): 3-38.

Van Nieukerken, E.J., Wagner, D.L., Baldessari, M., Mazzon, L., Angeli, G., Girolami, V., et al. 2012. *Antispila oinophylla* new species (Lepidoptera, Heliozelidae), a new North American grapevine leafminer invading Italian vineyards: taxonomy, DNA barcodes and life cycle. ZooKeys **170**: 29-77.

van Toor, R.F., Foster, S.P., Anstead, J.A., Mitchinson, S., Fenton, B., and Kasprowicz, L. 2008. Insecticide resistance and genetic composition of *Myzus persicae* (Hemiptera: Aphididae) on field potatoes in New Zealand. Crop Prot. **27**(2): 236-247.

Virgilio, M., Jordaens, K., Breman, F.C., Backeljau, T., and De Meyer, M. 2012. Identifying insects with incomplete DNA barcode libraries, African fruit flies (Diptera: Tephritidae) as a test case. PLOS ONE **7**(2): e31581.

Wang, J.-F., and Qiao, G.-X. 2009. DNA barcoding of genus *Toxoptera* Koch (Hemiptera: Aphididae): Identification and molecular phylogeny inferred from mitochondrial COI sequences. Insect Sci. **16**(6): 475-484.

Wei, S.-J., Mirab-Balou, M., Shi, B.-C., Gong, Y.-J., Liu, J., Kang, Z.-J., et al. 2010. External morphology and molecular identification of the newly found invasive pest *Echinothrips americanus* Morgan (Thysanoptera: Thripidae) in China. Acta Entomol. Sinica **53**(6): 715-715.

Wilson, J.-J., Sing, K.-W., and Sofian-Azirun, M. 2013. Building a DNA barcode reference library for the true butterflies (Lepidoptera) of Peninsula Malaysia: What about the subspecies? PLOS ONE **8**(11): e79969.

Woodcock, T.S., Boyle, E.E., Roughley, R.E., Kevan, P.G., Labbee, R.N., Smith, A.B., et al. 2013. The diversity and biogeography of the Coleoptera of Churchill: insights from DNA barcoding. BMC Ecol. **13**(40): 1472-6785.

Yang, Z.H., and Rannala, B. 1997. Bayesian phylogenetic inference using DNA sequences: A Markov Chain Monte Carlo method. Mol. Biol. Evol. **14**(7): 717-724.

Yassin, A., Capy, P., Madi-Ravazzi, L., Ogereau, D., and David, J.R. 2008. DNA barcode discovers two cryptic species and two geographical radiations in the invasive drosophilid *Zaprionus indianus*. Mol. Ecol. Resour. **8**(3): 491-501.

Yeh, W.B., Tseng, M.J., Chang, N.T., Wu, S.Y., and Tsai, Y.S. 2014. Development of species-specific primers for agronomical thrips and multiplex assay for quarantine identification of Western flower thrips. J. Econ. Entomol. **107**(5): 1728-1735.

Yilmaz, P., Kottmann, R., Field, D., Knight, R., Cole, J.R., Amaral-Zettler, L, et al. 2011. Minimum information about a marker gene sequence (MIMARKS) and minimum information about any (x) sequence (MIxS) specifications. Nat. Biotechnol. **29**:415–420.

Young, M.R., Behan-Pelletier, V.M., and Hebert, P.D.N. 2012. Revealing the hyperdiverse mite fauna of subarctic Canada through DNA barcoding. PLOS ONE **7**(11): e48755.

Zahiri, R., Lafontaine, J.D., Schmidt, B.C., Dewaard, J.R., Zakharov, E.V., and Hebert, P.D.N. 2014. A transcontinental challenge - a test of DNA barcode performance for 1,541 species of Canadian Noctuoidea (Lepidoptera). PLOS ONE **9**(3): e92797.

Zalucki, M.P., Shabbir, A., Silva, R., Adamson, D., Shu-Sheng, L., and Furlong, M.J. 2012. Estimating the economic cost of one of the world's major insect pests, *Plutella xylostella* (Lepidoptera: Plutellidae): Just how long is a piece of string? J. Econ. Entomol. **105**(4): 1115-1129.

Zhang, J., Kapli, P., Pavlidis, P., and Stamatakis, A. 2013. A general species delimitation method with applications to phylogenetic placements. Bioinformatics **29**(22): 2869-2876.

Table 1. Progress in the development of a DNA barcode reference library for regulated arthropod plant pests based on records in the Barcode of Life Data Systems (www.boldsystems.org) on December 22, 2015.

Order	Number of pest species[a]	Number of species with barcodes on BOLD (with single record)	Number of species in a single BIN [b]	Number of species with more than one BIN [b]	Number of species without a BIN [c]
Acari	8	4	1	1	2
Coleoptera	162	116 (17)	61	29	9
Diptera	42	38 (2)	24	11	1
Hemiptera	59	38 (4)	20	8	6
Hymenoptera	10	7 (1)	3	3	0
Lepidoptera	115	101 (10)	68	23	0
Orthoptera	3	2	0	2	0
Thysanoptera	10	8	1	7	0
Total	409	314 (34)	178	84	18

[a] Sources: CFIA, EPPO (A1 & A2 lists), NAPIS, USDA-APHIS and Global Invasive Species Database (100 of the world's worst invasive alien species).

[b] Only species with multiple records are included. Additional information is available in Table S1.

[c] Sequences with <500 bp, >1% ambiguous bases or with stop codons are not assigned a BIN.

Table 2. The number of Barcode Index Numbers (BINs) and maximum intraspecific sequence divergences (K2P) at COI for arthropod plant pests based on data in BOLD, the Barcode of Life Data Systems (www.boldsystems.org).

Order	Common name	Species	Barcode records	BINs	Maximum intraspecific divergence (%)
Acari	Red spider mite	*Tetranychus evansi*	6	2	3.0
Coleoptera	Oak splendour beetle	*Agrilus biguttatus*	7	2	22.0
	Citrus longhorned beetle	*Anoplophora chinensis*	33	3	4.6
	Boll weevil	*Anthonomus grandis*	119	3	7.8
	Strawberry bud weevil	*Anthonomus signatus*	12	3	4.3
	Spruce beetle	*Dendroctonus rufipennis*	10	4	5.5
	Northern corn rootworm	*Diabrotica barberi*	32	3	4.4
	Diaprepes root weevil	*Diaprepes abbreviatus*	79	13	10.9
	Lesser spruce shoot beetle	*Hylurgops palliatus*	21	4	5.5
	Alfalfa weevil	*Hypera postica*	16	2	5.6
	Six-toothed bark beetle	*Ips sexdentatus*	6	2	12.1
	European spruce bark beetle	*Ips typographus*	15	2	3.0
	White clover weevil	*Ischnopterapion virens*	10	2	4.6
	Sugarbeet wireworm	*Limonius californicus*	81	4	5.7
	Small white-marmorated longhorned beetle	*Monochamus sutor*	15	2	5.1
	Alfalfa snout beetle	*Otiorhynchus ligustici*	6	2	4.9
	Cereal leaf beetle	*Oulema melanopus*	16	3	8.7
	Six-toothed spruce bark beetle	*Pityogenes chalcographus*	14	4	8.7
	European oak bark beetle	*Scolytus intricatus*	17	6	11.5
	European spruce longhorn beetle	*Tetropium castaneum*	12	5	27.0
	Asian ambrosia beetle	*Xylosandrus crassiusculus*	5	3	11.0
Diptera	Guava fruit fly	*Anastrepha striata*	18	2	4.2
	Carambola fruit fly	*Bactrocera carambolae*	109	2	15.8
	Oriental fruit fly	*Bactrocera dorsalis*	645	5	10.4
	Asian fruit fly	*Bactrocera invadens*	230	2	8.4
	Olive fruit fly	*Bactrocera oleae*	107	3	8.6
	Peach fruit fly	*Bactrocera zonata*	42	4	10.6
	Vegetable leafminer	*Liriomyza sativae*	38	2	11.8
	American serpentine leafminer	*Liriomyza trifolii*	12	2	14.1
	Apple maggot	*Rhagoletis pomonella*	23	2	6.0
	European crane fly	*Tipula paludosa*	129	2	12.2
Hemiptera	Hemlock woolly adelgid	*Adelges tsugae*	150	4	8.3
	Silverleaf whitefly	*Bemisia tabaci*	918	16	20.0
	Green scale	*Coccus viridis*	5	2	16.8
	Brown marmorated stink bug	*Halyomorpha halys*	37	3	17.5
	Vine mealybug	*Planococcus ficus*	6	2	4.0
Hymenoptera	Oriental chestnut gall wasp	*Dryocosmus kuriphilus*	7	2	2.3
	Green alder sawfly	*Monsoma pulveratum*	18	2	3.8
Lepidoptera	Summer fruit tortrix moth	*Adoxophyes orana*	23	3	6.7
	Asiatic rice borer	*Chilo suppressalis*	57	3	18.9
	Yellow peach moth	*Conogethes punctiferalis*	202	3	8.9
	Mexican rice borer	*Eoreuma loftini*	8	2	3.1

	Oriental fruit moth	*Grapholita molesta*	56	2	6.2
	Old World bollworm	*Helicoverpa armigera*	433	2	3.2
	Hemlock looper	*Lambdina fiscellaria*	570	3	3.7
	Pea blue	*Lampides boeticus*	126	2	8.8
	Soybean pod borer	*Leguminivora glycinivorella*	17	2	3.7
	Brinjal borer	*Leucinodes orbonalis*	159	6	8.0
	Pear leaf blister moth	*Leucoptera malifoliella*	5	2	3.6
	Rosy moth	*Lymantria mathura*	41	2	9.2
	Soybean pod borer	*Maruca vitrata*	633	4	9.2
	Bruce spanworm	*Operophtera bruceata*	353	2	5.8
	Lime swallowtail	*Papilio demoleus*	33	3	11.0
	Tufted apple bud moth	*Platynota idaeusalis*	242	2	3.7
	Fall armyworm	*Spodoptera frugiperda*	6	2	1.7
	Oak processionary moth	*Thaumetopoea processionea*	7	2	1.9
Orthoptera	Mormon cricket	*Anabrus simplex*	72	3	11.3
Thysanoptera	European flower thrips	*Frankliniella intonsa*	27	2	3.4
	Western flower thrips	*Frankliniella occidentalis*	457	4	3.9
	Chili Thrips	*Scirtothrips dorsalis*	233	12	18.0
	Melon thrips	*Thrips palmi*	212	2	13.0

Species with at least 5 publicly available sequences on BOLD were included in the analysis. Additional information is provided in Table S1.

Table 3. Arthropod plant pests reported as representing a cryptic species complex following DNA barcode analysis.

Order	Common name	Species	Max. diver-gence (%)	NJ/ phylog-enetic Clades	Reference
Acari	Kanzawa spider mite	*Tetranychus kanzawai*	4.7[a]	2	Matsuda et al. 2013
	NA	*Tetranychus parakanzawai*	5.1[a]	2	"
Coleoptera	Bark beetle	*Crypturgus subcribrosus*	6.7[a]	2	Jordal and Kambestad 2014
	Bark beetle	*Crypturgus hispidulus*	6.8[a]	2	"
	Hairy spruce bark beetle	*Dryocoetes autographus*	9.8[a]	3	"
	Bark beetle	*Dryocoetes hectographus*	5.2[a]	3	"
	Lesser spruce shoot beetle	***Hylurgops palliatus***	5.7[a]	3	"
	Engraver beetle	*Ips acuminatus*	9.7[a]	2	"
	Bark beetle	*Orthotomicus suturalis*	5.6[a]	2	"
	Striped Ambrosia Beetle	*Trypodendron lineatum*	4.6[a]	2	"
	Fruit-tree pinhole borer	*Xyleborinus saxeseni*	12.5[a]	2	"
	Ambrosia beetle	*Xyleborus affinis*	20.1[b]	3	Chang et al. 2014
	Wireworm	*Hypnoidus bicolor*	3.0[a]	3	Etzler et al. 2014
	Yellow toadflax stem weevil	*Mecinus janthinus*	2.4[a]	2	ToŠEvski et al. 2011
	Coffee berry borer	*Hypothenemus hampei*	11.8[a]	4	Gauthier 2010
	Coconut leaf beetle	***Brontispa longissima***	3.0[b]	2	Takano et al. 2011
	Root weevil	***Diaprepes abbreviatus***	14.9[a]	3	Ascunce et al. 2008
Diptera	Hessian fly	*Mayetiola destructor*	3.0[b]	2	Johnson et al. 2012
	African fig fly	*Zaprionus indianus*	11.2[a]	2	Yassin et al. 2008
	Blueberry gall midge	*Dasineura oxycoccana*	10.7[c]	2	Mathur et al. 2012
	Glasshouse Striped Sciarid	*Bradysia ocellaris*	2.4[b]	2	Shin et al. 2015
Hemiptera	Citrus mealybug	*Planococcus citri*	NA	2	Abd-Rabou et al. 2012
	Solenopsis mealybug	*Phenacoccus solenopsis*	3.0[b]	2	Dong et al. 2009
	Apple mealybug	*Phenacoccus aceris*	5.6[b]	2	Park et al. 2011*a*
	Matsumoto mealybug	*Crisicoccus matsumotoi*	4.0[b]	2	"
	Cyanotis scale	*Aspidiotus excises*	4.6[b]	2	"
	Silverleaf whitefly	***Bemisia tabaci***	20[b]	15	Ashfaq et al. 2014
	Mottled arum aphid	*Neomyzus circumflexus*	3.1[b]	2	Foottit et al. 2008
	Leaf curl plum aphid	*Brachycaudus helichrysi*	2.5[b]	2	Rebijith et al. 2013
	Cabbage aphid	*Brevicoryne brassicae*	3.8[b]	2	"
	Asian sowthistle aphid	*Hyperomyzus carduellinus*	3.0[b]	2	"
	Aphid	*Toxoptera aurantii*	3.1[b]	2	Wang and Qiao 2009

	Bronze bug	*Thaumastocoris peregrinus*	8.7[b]	3	Nadel et al. 2010
Lepidoptera	Grapewine leafminer	*Antispila hydrangaeella*	5.2[b]	2	Van Nieukerken et al. 2012
	Durian fruit borer	***Conogethes punctiferalis***	5.8[b]	2	Shashank et al. 2014
	Leaf worm	*Copitarsia decolora*	4.2[a]	2	Simmons and Scheffer 2004
	Asian gypsy moth	***Lymantria dispar***	3.1[b]	2	Ball and Armstrong 2006
	Pink gypsy moth	***Lymantria mathura***	4.7[b]	2	"
		Lymantria sinica	2.9[b]	2	deWaard et al. 2010
	Beet armyworm	*Spodoptera exigua*	NA	2	Dumas et al. 2015
	Paddy armyworm	*S. mauritia*	NA	2	"
Thysanoptera	Western flower thrips	***Frankliniella occidentalis***	4.4[b]	2	Rugman-Jones et al. 2010
	Melon thrips	***Thrips palmi***	19.9[b]	4	Rebijith et al. 2014; Kadirvel et al. 2013; Iftikhar et al. 2016
	Onion thrips	*T. tabaci*	10.4[b]	3	"
	Chili thrips	***Scirtothrips dorsalis***	20.8[b]	11	Dickey et al. 2015; Iftikhar et al. 2016
	Black flower thrips	*Haplothrips reuteri*	3.7[b]	2	Iftikhar et al. 2016

The citations were collected by literature survey on the Web of Science with search terms "DNA barcoding pest cryptic" (accessed 12 January 2016). The citations were further restricted by only considering studies explicitly COI-5′ and reporting cryptic species. Species also included in the five pest databases (Table S1) are bold faced.

[a] p-distances; [b] K2P distances; [c] GTRpG; NA = Information not available

Table S1. Arthropod plant pests listed on multiple databases and their DNA barcoding status on BOLD (

Common name	Species	Order	Barcode records o
City longhorn beetle	*Aeolesthes sarta*	Coleoptera	7
Small Hive Beetle	*Aethina tumida*	Coleoptera	5
St. Johnswort Borer	*Agrilus hyperici*	Coleoptera	4
Emerald Ash Borer	*Agrilus planipennis*	Coleoptera	16
Jewel Beetle	*Agrilus sulcicollis*	Coleoptera	16
Wireworm	*Agriotes sputator*	Coleoptera	24
Wireworm	*Agriotes ustulatus*	Coleoptera	25
Asian Longhorned Beetle	*Anoplophora glabripennis*	Coleoptera	443
Brown mulberry longhorn beet	*Apriona germari*	Coleoptera	13
na	*Apriona rugicollis*	Coleoptera	1
Red Neck Longhorn Beetle	*Aromia bungii*	Coleoptera	2
Oak Timberworm	*Arrhenodes minutus*	Coleoptera	4
Coconut hispid beetle	*Brontispa longissima*	Coleoptera	124
Plum curculio	*Conotrachelus nenuphar*	Coleoptera	13
European Chestnut Weevil	*Curculio elephas*	Coleoptera	9
Great Spruce Bark Beetle	*Dendroctonus micans*	Coleoptera	8
Mountain Pine Beetle (MPB)	*Dendroctonus ponderosae*	Coleoptera	110
Douglas-fir beetle	*Dendroctonus pseudotsugae*	Coleoptera	4
Cucurbit Beetle	*Diabrotica speciosa*	Coleoptera	5
Spotted cucumber beetle	*Diabrotica undecimpunctata*	Coleoptera	24
Western Corn Rootworm	*Diabrotica virgifera*	Coleoptera	19
Potato Flea Beetle	*Epitrix cucumeris*	Coleoptera	17
na	*Epitrix similaris*	Coleoptera	4
Western Potato Flea Beetle	*Epitrix subcrinita*	Coleoptera	1
Tuber Flea beetle	*Epitrix tuberis*	Coleoptera	5
Black pine bark beetle	*Hylastes ater*	Coleoptera	1
Large Pine Weevil	*Hylobius abietis*	Coleoptera	17
Redhaired Pine Bark Beetle	*Hylurgus ligniperda*	Coleoptera	6
Pine Engraver Beetle	*Ips pini*	Coleoptera	3
Colorado Potato Beetle	*Leptinotarsa decemlineata*	Coleoptera	25
Lily Leaf Beetle	*Lilioceris lilii*	Coleoptera	12
Argentine Stem Weevil	*Listronotus bonariensis*	Coleoptera	20
Asiatic Garden Beetle	*Maladera castanea*	Coleoptera	1
Corn wireworm	*Melanotus communis*	Coleoptera	1
Japanese Pine Sawyer	*Monochamus alternatus*	Coleoptera	14
Northeastern sawyer	*Monochamus notatus*	Coleoptera	1
Sakhalin Pine Sawyer	*Monochamus saltuarius*	Coleoptera	1
White-spotted sawyer	*Monochamus scutellatus*	Coleoptera	27
Whitefringed Weevil	*Naupactus leucoloma*	Coleoptera	74
Fruit tree weevil	*Naupactus xanthographus*	Coleoptera	116
Lemon tree borer	*Oemona hirta*	Coleoptera	3
European Elm Flea Weevil	*Orchestes alni*	Coleoptera	83
Mediterranean Pine Engraver	*Orthotomicus erosus*	Coleoptera	2
Coconut Rhinoceros Beetle	*Oryctes rhinoceros*	Coleoptera	1
white pine weevil	*Pissodes strobi*	Coleoptera	3

Oak Ambrosia Beetle	*Platypus quercivorus*	Coleoptera	8
Four-eyed fir bark beetle	*Polygraphus proximus*	Coleoptera	4
Japanese Beetle	*Popillia japonica*	Coleoptera	24
Viburnum Leaf Beetle	*Pyrrhalta viburni*	Coleoptera	41
New Guinea sugarcane weevil	*Rhabdoscelus obscurus*	Coleoptera	1
South American Palm Weevil	*Rhynchophorus palmarum*	Coleoptera	2
Poplar Borer	*Saperda calcarata*	Coleoptera	9
Morawitz's bark beetle	*Scolytus morawitzi*	Coleoptera	4
European Elm Bark Beetle	*Scolytus scolytus*	Coleoptera	1
Mango seed weevil	*Sternochetus mangiferae*	Coleoptera	5
Brown Spruce Longhorn Beetle	*Tetropium fuscum*	Coleoptera	7
Pine Shoot Beetle	*Tomicus destruens*	Coleoptera	1
Pine Shoot Beetle	*Tomicus piniperda*	Coleoptera	20
Velvet Longhorned Beetle	*Trichoferus campestris*	Coleoptera	6
Khapra Beetle	*Trogoderma granarium*	Coleoptera	31
Pear Blight Beetle	*Xyleborus dispar*	Coleoptera	83
Redbay Ambrosia Beetle	*Xyleborus glabratus*	Coleoptera	4
Rustic Borer	*Xylotrechus colonus*	Coleoptera	11
Oak Splendour Beetle	*Agrilus biguttatus*	Coleoptera	7
Ambrosia Beetle	*Anisandrus maiche*	Coleoptera	4
Alfalfa Weevil	*Hypera postica*	Coleoptera	16
Sixtoothed Bark Beetle	*Ips sexdentatus*	Coleoptera	6
European spruce bark beetle	*Ips typographus*	Coleoptera	15
White clover weevil	*Ischnopterapion virens*	Coleoptera	10
Small white-marmorated	*Monochamus sutor*	Coleoptera	15
Alfalfa Snout Beetle	*Otiorhynchus ligustici*	Coleoptera	6
Banded Elm Bark Beetle	*Scolytus schevyrewi*	Coleoptera	3
Lesser Pine Shoot Beetle	*Tomicus minor*	Coleoptera	4
Citrus long-horned beetle	*Anoplophora chinensis*	Coleoptera	33
Boll Weevil (BW)	*Anthonomus grandis*	Coleoptera	119
Strawberry Clipper	*Anthonomus signatus*	Coleoptera	12
Northern Corn Rootworm	*Diabrotica barberi*	Coleoptera	32
Cereal Leaf Beetle (CLB)	*Oulema melanopus*	Coleoptera	16
Granulate Ambrosia Beetle	*Xylosandrus crassiusculus*	Coleoptera	5
The spruce beetle	*Dendroctonus rufipennis*	Coleoptera	10
Lesser Spruce Shoot Beetle	*Hylurgops palliatus*	Coleoptera	21
Ambrosia Beetle	*Limonius californicus*	Coleoptera	81
Sixtoothed Spruce Bark Beetle	*Pityogenes chalcographus*	Coleoptera	14
European spruce longhorn bee	*Tetropium castaneum*	Coleoptera	12
European Oak Bark Beetle	*Scolytus intricatus*	Coleoptera	17
Diaprepes Root Weevil	*Diaprepes abbreviatus*	Coleoptera	79
Pepper Weevil	*Anthonomus eugenii*	Coleoptera	2
Nut weevil	*Curculio nucum*	Coleoptera	1
Roundheaded pine beetle	*Dendroctonus adjunctus*	Coleoptera	3
Western pine beetle	*Dendroctonus brevicomis*	Coleoptera	2
Southern Pine Beetle	*Dendroctonus frontalis*	Coleoptera	2
Coffee berry borer	*Hypothenemus hampei*	Coleoptera	26

West Indian Cane Weevil	*Metamasius hemipterus*	Coleoptera		1
Red palm weevil	*Rhynchophorus ferrugineus*	Coleoptera		314
Chinese rose beetle	*Adoretus sinicus*	Coleoptera	na	
Bronze Birch Borer	*Agrilus anxius*	Coleoptera		14
Goldspotted Oak Borer	*Agrilus auroguttatus*	Coleoptera	na	
Oriental Beetle	*Anomala orientalis*	Coleoptera		5
Chafer beetle	*Anomala sulcatula*	Coleoptera	na	
strawberry weevil	*Anthonomus bisignifer*	Coleoptera		1
Poplar Stem Borer	*Apriona cinerea*	Coleoptera	na	
Oriental beetle	*Blitopertha orientalis*	Coleoptera	na	
Rough Sweetpotato Weevil	*Blosyrus asellus*	Coleoptera	na	
Japanese Cedar Longhorned Be	*Callidiellum rufipenne*	Coleoptera		1
Brown Fir Longhorned Beetle	*Callidiellum villosulum*	Coleoptera		1
Bamboo Borer	*Chlorophorus annularis*	Coleoptera	na	
Slender-Banded Pinecone Long	*Chlorophorus strobilicola*	Coleoptera	na	
Click beetle	*Conoderes rufangulus*	Coleoptera	na	
Small avocado seed weevil	*Conotrachelus aguacatae*	Coleoptera	na	
Avocado stem weevil	*Copturus aguacatae*	Coleoptera	na	
Pecan Weevil	*Curculio caryae*	Coleoptera		5
Soybean Stem Borer	*Dectes texanus*	Coleoptera	na	
Western balsam bark beetle	*Dryocoetes confusus*	Coleoptera		5
Fijian ginger weevil	*Elytroteinus subtruncatus*	Coleoptera	na	
Mexican Bean Beetle	*Epilachna varivestis*	Coleoptera		1
West Indian sweet potato wee	*Euscepes postfasciatus*	Coleoptera	na	
Leaf beetle	*Exosoma lusitanica*	Coleoptera	na	
Tuberous pine weevil	*Geniocremnus chilensis*	Coleoptera	na	
Western hemlock wood stainer	*Gnathotrichus sulcatus*	Coleoptera	na	
Eucalyptus snout beetle	*Gonipterus gibberus*	Coleoptera	na	
Eucalyptus snout beetle	*Gonipterus scutellatus*	Coleoptera	na	
Avocado seed weevil	*Heilipus lauri*	Coleoptera	na	
Black Maize Beetle	*Heteronychus arator*	Coleoptera	na	
White grub	*Holotrichia mindanaona*	Coleoptera	na	
Loosestrife Root Weevil	*Hylobius transversovittus*	Coleoptera	na	
Sixspined Ips	*Ips calligraphus*	Coleoptera	na	
Pinyon Ips Beetle	*Ips confusus*	Coleoptera		1
Five-spined bark beetle	*Ips grandicollis*	Coleoptera		3
Kyrgyz mountain engraver	*Ips hauseri*	Coleoptera	na	
Arizona five-spined engraver	*Ips lecontei*	Coleoptera	na	
California pine engraver	*Ips plastographus*	Coleoptera	na	
Scolytid Beetle	*Ips subelongatus*	Coleoptera	na	
Chilean vegetable weevil	*Listroderes subcinctus*	Coleoptera	na	
Ambrosia beetle	*Megaplatypus mutatus*	Coleoptera		1
Hemlock Borer	*Melanophila fulvoguttata*	Coleoptera		12
Pine sawyer beetle	*Monochamus carolinensis*	Coleoptera		15
Balsam fir sawyer	*Monochamus marmorator*	Coleoptera		5
Spotted Pine Sawyer	*Monochamus mutator*	Coleoptera		4
Japanese pine sawyer beetle	*Monochamus nitens*	Coleoptera	na	

Flat-faced longhorn beetle	*Monochamus obtusus*	Coleoptera		3
Southern Pine Sawyer	*Monochamus titillator*	Coleoptera		6
Locust Leafminer	*Odontota dorsalis*	Coleoptera		10
Wingless Weevil	*Otiorhynchus dieckmanni*	Coleoptera	na	
Eastern pine weevil	*Pissodes nemorensis*	Coleoptera	na	
Lodgepole terminal weevil	*Pissodes terminalis*	Coleoptera		1
Bark Beetle	*Pityoborus comatus*	Coleoptera	na	
Walnut Twig Beetle	*Pityophthorus juglandis*	Coleoptera		3
Andean potato weevil	*Premnotrypes latithorax*	Coleoptera	na	
Andean potato weevil	*Premnotrypes suturicallus*	Coleoptera	na	
Andean potato weevil	*Premnotrypes vorax*	Coleoptera	na	
Twobanded Japanese Weevil	*Pseudocneorhinus bifasciatus*	Coleoptera	na	
Small oak bark beetle	*Pseudopityophthorus minutissimus*	Coleoptera		2
European Chafer (EC)	*Rhizotrogus majalis*	Coleoptera	na	
Roundheaded Appletree Borer	*Saperda candida*	Coleoptera		10
Hemlock Woolly Adelgid Lady E	*Sasajiscymnus tsugae*	Coleoptera	na	
Ladybird Beetle	*Stethorus punctum*	Coleoptera	na	
Thin-antenna spruce borer	*Tetropium gracilicorne*	Coleoptera	na	
Altai larch longhorn beetle	*Xylotrechus altaicus*	Coleoptera	na	
Mulberry Borer	*Xylotrechus chinensis*	Coleoptera	na	
Namangan longhorn beetle	*Xylotrechus namanganensis*	Coleoptera	na	
Longhorned Beetle	*Xylotrechus pyrrhoderus*	Coleoptera	na	
Coffee White Stem Borer Beetl	*Xylotrechus quadripes*	Coleoptera	na	
South American cucurbit fruit f	*Anastrepha grandis*	Diptera		3
Mexican fruit fly	*Anastrepha ludens*	Diptera		68
West indian fruit fly	*Anastrepha obliqua*	Diptera		52
Sapote fruit fly	*Anastrepha serpentina*	Diptera		8
Fruit fly	*Bactrocera caryeae*	Diptera		1
Guava Fruit Fly	*Bactrocera correcta*	Diptera		54
Cucumber fruit fly	*Bactrocera cucumis*	Diptera		2
Melon Fly	*Bactrocera cucurbitae*	Diptera		221
Fruit fly	*Bactrocera kandiensis*	Diptera		17
Malaysian Fruit Fly	*Bactrocera latifrons*	Diptera		81
Chinese citrus fly	*Bactrocera minax*	Diptera		58
Fruit fly	*Bactrocera occipitalis*	Diptera		30
Asian Papaya Fruit Fly	*Bactrocera papayae*	Diptera		64
Fruit fly	*Bactrocera philippinensis*	Diptera		19
Queensland fruit fly	*Bactrocera tryoni*	Diptera		48
Japanese orange fly	*Bactrocera tsuneonis*	Diptera		21
Natal fruit fly	*Ceratitis rosa*	Diptera		40
Lesser pumpkin fly	*Dacus ciliatus*	Diptera		40
Spotted Wing Drosophila	*Drosophila suzukii*	Diptera		133
Sout American leaf miner	*Liriomyza huidobrensis*	Diptera		13
Blotch leaf miner	*Nemorimyza maculosa*	Diptera		2
Eastern Cherry Fruit Fly	*Rhagoletis cingulata*	Diptera		23
Black cherry fruit fly	*Rhagoletis fausta*	Diptera		1
Blueberry Maggot	*Rhagoletis mendax*	Diptera		2

papaya fruit fly	*Toxotrypana curvicauda*	Diptera		6
Guava fruit fly	*Anastrepha striata*	Diptera		18
Carambola Fruit Fly	*Bactrocera carambolae*	Diptera		109
Asian fruit fly	*Bactrocera invadens*	Diptera		230
Mediterranean fruit fly, Medfly	*Ceratitis capitata*	Diptera		199
Vegetable leaf miner	*Liriomyza sativae*	Diptera		38
American serpentine leafminer	*Liriomyza trifolii*	Diptera		12
Apple Maggot	*Rhagoletis pomonella*	Diptera		23
European Crane Fly	*Tipula paludosa*	Diptera		129
Olive Fruit Fly	*Bactrocera oleae*	Diptera		107
Peach fruit fly	*Bactrocera zonata*	Diptera		42
Oriental fruit fly	*Bactrocera dorsalis*	Diptera		645
Caribbean Fruit Fly; Carib Fly	*Anastrepha suspensa*	Diptera		2
Fruit fly	*Bactrocera pyrifoliae*	Diptera	na	
Swede Midge	*Contarinia nasturtii*	Diptera		3
South American Rice Miner	*Hydrellia wirthi*	Diptera	na	
Western Cherry Fruit Fly	*Rhagoletis indifferens*	Diptera	na	
Canadian larch cone fly	*Strobilomyia viaria*	Diptera	na	
Orange spiny whitefly	*Aleurocanthus spiniferus*	Hemiptera		1
Soybean Aphid	*Aphis glycines*	Hemiptera		205
Elm Seed Bug	*Arocatus melanocephalus*	Hemiptera		1
Bagrada Bug	*Bagrada hilaris*	Hemiptera		29
Japanese Wax Scale	*Ceroplastes japonicus*	Hemiptera		31
Cypress aphid	*Cinara cupressi*	Hemiptera		18
Asian citrus psyllid	*Diaphorina citri*	Hemiptera		10
Russian Wheat Aphid (RWA)	*Diuraphis noxia*	Hemiptera		129
Glassy-winged Sharpshooter	*Homalodisca vitripennis*	Hemiptera		6
Spotted Lanternfly	*Lycorma delicatula*	Hemiptera		7
Hibiscus (Pink) Mealybug	*Maconellicoccus hirsutus*	Hemiptera		3
Bean Plataspid	*Megacopta cribraria*	Hemiptera		47
Sugarcane spotted aleyrodid	*Neomaskellia bergii*	Hemiptera		1
San Jose scale	*Quadraspidiotus perniciosus*	Hemiptera		2
Pine Tortoise Scale	*Toumeyella parvicornis*	Hemiptera		2
Brown Citrus Aphid	*Toxoptera citricidus*	Hemiptera		8
Arrowhead Scale	*Unaspis yanonensis*	Hemiptera		8
Green scale	*Coccus viridis*	Hemiptera		5
Vine Mealybug	*Planococcus ficus*	Hemiptera		6
Brown Marmorated Stink Bug	*Halyomorpha halys*	Hemiptera		37
Hemlock Woolly Adelgid	*Adelges tsugae*	Hemiptera		150
Sweetpotato Whitefly (SPWf)	*Bemisia tabaci*	Hemiptera		918
Grass Sharpshooter	*Draeculacephala minerva*	Hemiptera		1
Blue-green Sharpshooter	*Graphocephala atropunctata*	Hemiptera		16
Mealybug	*Hypogeococcus pungens*	Hemiptera		1
Coffee Mealybug	*Planococcus lilacinus*	Hemiptera		1
Passionvine Mealybug	*Planococcus minor*	Hemiptera		2
Blue grey fly	*Aleurocanthus woglumi*	Hemiptera	na	
Psyllid	*Bactericera cockerelli*	Hemiptera	na	

Soft Wax Scale	*Ceroplastes destructor*	Hemiptera		5
Iceryine Scale	*Crypticerya multicicatrices*	Hemiptera	na	
Cocoa Mealybug	*Exallomochlus hispidus*	Hemiptera	na	
Elongate Hemlock Scale	*Fiorinia externa*	Hemiptera	na	
Coconut red scale	*Furcaspis oceanica*	Hemiptera	na	
Pallid cane leafhopper	*Haplaxius crudus*	Hemiptera	na	
Egyptian fluted scale	*Icerya aegyptiaca*	Hemiptera		1
Cottony Cushion Scale	*Icerya purchasi*	Hemiptera		5
Ussuri oystershell scale	*Lepidosaphes ussuriensis*	Hemiptera	na	
Paddy bug	*Leptocorisa acuta*	Hemiptera		7
Brown Chilean leaf-footed bug	*Leptoglossus chilensis*	Hemiptera	na	
Japanese maple scale	*Lopholeucaspis japonica*	Hemiptera		3
Margarodid	*Margarodes prieskaensis*	Hemiptera	na	
Grape ground pearl	*Margarodes vitis*	Hemiptera	na	
Ground pearl	*Margarodes vredendalensis*	Hemiptera	na	
Wheat Bug	*Nysius huttoni*	Hemiptera		4
Cotton seed bug	*Oxycarenus Hyalinipennis*	Hemiptera	na	
Lobate Lac Scale	*Paratachardina pseudolobata*	Hemiptera	na	
Black Parlatoria Scale	*Parlatoria ziziphi*	Hemiptera		5
Cassava mealybug	*Phenococcus manihoti*	Hemiptera	na	
Euphorbia Pit Scale	*Planchonia stentae*	Hemiptera		14
White Peach Scale	*Pseudaulacaspis pentagona*	Hemiptera		12
Cottony Citrus Scale	*Pulvinaria polygonata*	Hemiptera	na	
Mealybug	*Ripersiella hibisci*	Hemiptera	na	
White-banded elm leafhopper	*Scaphoideus luteolus*	Hemiptera	na	
Rice Stinkbug	*Tibraca limbativentris*	Hemiptera		1
Twospotted Citrus Psyllid	*Trioza erytreae*	Hemiptera	na	
Citrus snow scale	*Unaspis citri*	Hemiptera	na	
Grapevine phylloxera	*Viteus vitifoliae*	Hemiptera		7
Red-headed sharpshooter	*Xyphon fulgidum*	Hemiptera	na	
European Pine Sawfly	*Neodiprion sertifer*	Hymenoptera		4
Sirex Wasp	*Sirex noctilio*	Hymenoptera		33
Giant Wood Wasp	*Urocerus gigas*	Hymenoptera		3
Chestnut gall wasp	*Dryocosmus kuriphilus*	Hymenoptera		7
Green Alder Sawfly	*Monsoma pulveratum*	Hymenoptera		18
Tremex Woodwasp	*Tremex fuscicornis*	Hymenoptera		2
Scarlet Oak Sawfly	*Caliroa quercuscoccineae*	Hymenoptera	na	
Horned Oak Gall Wasp	*Callirhytis cornigera*	Hymenoptera	na	
Erythrina Gall Wasp	*Quadrastichus erythrinae*	Hymenoptera	na	
Blue-black horntail	*Sirex ermak*	Hymenoptera		1
Western black-headed bud wo	*Acleris gloverana*	Lepidoptera		1
Eastern black-headed budworr	*Acleris variana*	Lepidoptera		118
Leek Moth	*Acrolepiopsis assectella*	Lepidoptera		24
Black Cutworm (BCw)	*Agrotis ipsilon*	Lepidoptera		130
Fruit Tree Tortrix	*Archips podana*	Lepidoptera		9
Cherry Blossom Moth	*Argyresthia pruniella*	Lepidoptera		19
Polyphagous leaf roller	*Argyrotaenia ljungiana*	Lepidoptera		6

Silver Y Moth	*Autographa gamma*	Lepidoptera	31
Cactus Moth	*Cactoblastis cactorum*	Lepidoptera	9
Geranium bronze	*Cacyreus marshalli*	Lepidoptera	14
Peach Fruit Moth	*Carposina sasakii*	Lepidoptera	82
Large aspen tortrix	*Choristoneura conflictana*	Lepidoptera	316
Eastern spruce budworm	*Choristoneura fumiferana*	Lepidoptera	111
The oblique banded leaf roller	*Choristoneura rosaceana*	Lepidoptera	157
Golden Twin Spot Moth	*Chrysodeixis chalcites*	Lepidoptera	11
Cocoa pod borer	*Conopomorpha cramerella*	Lepidoptera	106
Hickory Shuckworm (HSw)	*Cydia caryana*	Lepidoptera	13
Codling Moth (CM)	*Cydia pomonella*	Lepidoptera	141
Nut fruit tortix	*Cydia splendana*	Lepidoptera	11
Nettle Caterpillar	*Darna pallivitta*	Lepidoptera	1
Pine-tree Lappet	*Dendrolimus pini*	Lepidoptera	28
Sakhalin Silk Moth	*Dendrolimus superans*	Lepidoptera	24
Yellow peach moth	*Dichocrocis punctiferalis*	Lepidoptera	1
Zimmerman Pine Moth	*Dioryctria zimmermani*	Lepidoptera	1
European Pepper Moth	*Duponchelia fovealis*	Lepidoptera	3
Onion carpenter worm	*Dyspessa ulula*	Lepidoptera	1
Spotted bollworm - cotton	*Earias vittella*	Lepidoptera	7
Cherry Bark Tortrix	*Enarmonia formosana*	Lepidoptera	3
Light Brown Apple Moth	*Epiphyas postvittana*	Lepidoptera	1433
Mottled Umber Moth	*Erannis defoliaria*	Lepidoptera	29
Fruit Piercing Moth	*Eudocima fullonia*	Lepidoptera	7
European Grape Berry Moth	*Eupoecilia ambiguella*	Lepidoptera	6
Plum fruit moth	*Grapholita funebrana*	Lepidoptera	14
European Poplar Shoot Borer	*Gypsonoma aceriana*	Lepidoptera	31
Corn earworm	*Helicoverpa zea*	Lepidoptera	165
Fall Webworm	*Hyphantria cunea*	Lepidoptera	152
Tomato Pinworm	*Keiferia lycopersicella*	Lepidoptera	1
Brinjal Fruit and Shoot Borer	*Leucinodes africensis*	Lepidoptera	28
na	*Leucinodes pseudorbonalis*	Lepidoptera	1
na	*Leucinodes rimavallis*	Lepidoptera	2
Satin Moth	*Leucoma salicis*	Lepidoptera	77
European Grapevine Moth	*Lobesia botrana*	Lepidoptera	1
Okinawa gypsy moth	*Lymantria albescens*	Lepidoptera	14
Asian Gypsy Moth	*Lymantria dispar*	Lepidoptera	343
Nun Moth	*Lymantria monacha*	Lepidoptera	85
Hokkaido gypsy moth	*Lymantria umbrosa*	Lepidoptera	21
Iris Borer	*Macronoctua onusta*	Lepidoptera	8
Eastern tent caterpillar	*Malacosoma americanum*	Lepidoptera	46
Forest Tent Caterpillar	*Malacosoma disstria*	Lepidoptera	116
Sweetpotato vine borer	*Omphisa anastomosalis*	Lepidoptera	1
Winter Moth	*Operophtera brumata*	Lepidoptera	379
Douglas-fir tussock moth	*Orgyia pseudotsugata*	Lepidoptera	172
Asian Corn Borer	*Ostrinia furnacalis*	Lepidoptera	29
European Corn Borer	*Ostrinia nubilalis*	Lepidoptera	74

Spring Cankerworm	*Paleacrita vernata*	Lepidoptera		85
Chestnut leafroller	*Pammene fasciana*	Lepidoptera		5
Stalk Borer	*Papaipema nebris*	Lepidoptera		16
Palm moth	*Paysandisia archon*	Lepidoptera		2
Pink bollworm - cotton	*Pectinophora gossypiella*	Lepidoptera		20
Pink-spotted bollworm	*Pectinophora scutigera*	Lepidoptera		3
Poinciana Looper	*Pericyma cruegeri*	Lepidoptera		5
Potato Tuberworm	*Phthorimaea operculella*	Lepidoptera		12
Large White Butterfly - brassic	*Pieris brassicae*	Lepidoptera		78
European Pine Shoot Moth(EPS	*Rhyacionia buoliana*	Lepidoptera		5
Southern armyworm	*Spodoptera eridania*	Lepidoptera		41
Egyptian Cottonworm	*Spodoptera littoralis*	Lepidoptera		26
Cotton Cutworm	*Spodoptera litura*	Lepidoptera		80
Western Bean Cutworm	*Striacosta albicosta*	Lepidoptera		7
Red-belted Clearwing	*Synanthedon myopaeformis*	Lepidoptera		4
False codling moth	*Thaumatotibia leucotreta*	Lepidoptera		36
Green Oak Tortrix	*Tortrix viridana*	Lepidoptera		11
Tomato Leaf Miner	*Tuta absoluta*	Lepidoptera		34
Apple Ermine Moth (AEM)	*Yponomeuta malinellus*	Lepidoptera		18
Mexican Rice Borer	*Eoreuma loftini*	Lepidoptera		8
Oriental Fruit Moth (OFM)	*Grapholita molesta*	Lepidoptera		56
Old World Bollworm - cotton	*Helicoverpa armigera*	Lepidoptera		433
Bean butterfly	*Lampides boeticus*	Lepidoptera		126
Soybean Pod Borer	*Leguminivora glycinivorella*	Lepidoptera		17
Pear leaf blister moth	*Leucoptera malifoliella*	Lepidoptera		5
Rosy Gypsy Moth	*Lymantria mathura*	Lepidoptera		41
Squash Vine Borer	*Melittia cucurbitae*	Lepidoptera		3
Tomato Fruit Borer	*Neoleucinodes elegantalis*	Lepidoptera		4
Bruce Spanworm	*Operophtera bruceata*	Lepidoptera		350
Tufted Apple Bud Moth (TABM	*Platynota idaeusalis*	Lepidoptera		242
Fall Armyworm	*Spodoptera frugiperda*	Lepidoptera		6
Oak Processionary Moth	*Thaumetopoea processionea*	Lepidoptera		7
Summer fruit tortrix moth	*Adoxophyes orana*	Lepidoptera		23
Asiatic Rice Borer	*Chilo suppressalis*	Lepidoptera		57
Yellow Peach Moth; Castor Cap	*Conogethes punctiferalis*	Lepidoptera		202
Hemlock Looper	*Lambdina fiscellaria*	Lepidoptera		566
Lime Swallowtail	*Papilio demoleus*	Lepidoptera		33
Legume pod borer	*Maruca vitrata*	Lepidoptera		633
Eggplant borer	*Leucinodes orbonalis*	Lepidoptera		159
Pecan Nut Casebearer	*Acrobasis nuxvorella*	Lepidoptera		6
Apple Tortrix	*Archips fuscocupreanus*	Lepidoptera		21
Variegated Golden Tortrix	*Archips xylosteanus*	Lepidoptera	na	
Carnation Leaf Roller	*Cacoecimorpha pronubana*	Lepidoptera		25
Leafroller	*Capua tortrix*	Lepidoptera	na	
Peach fruit moth	*Carposina niponensis*	Lepidoptera	na	
Carpenter Worm	*Chilecomadia valdiviana*	Lepidoptera		7
Western Spruce Budworm	*Choristoneura freemani*	Lepidoptera	na	

Cabbage Cluster Caterpillar	*Crocidolomia binotalis*	Lepidoptera	na	
Bud Borer	*Crocidosema aporema*	Lepidoptera		59
Manchurian fruit moth	*Cydia inopinata*	Lepidoptera	na	
Cherry fruitworm	*Cydia packardi*	Lepidoptera	na	
Lesser appleworm	*Cydia prunivora*	Lepidoptera	na	
Siberian coniferous silk moth	*Dendrolimus sibiricus*	Lepidoptera	na	
Walnut moth	*Erschoviella musculana*	Lepidoptera	na	
White-winged gypsy moth	*Lymantria postalba*	Lepidoptera	na	
Mountain tent caterpillar	*Malacosoma parallela*	Lepidoptera	na	
Pear fruit moth	*Numonia pyrivorella*	Lepidoptera	na	
Banana Moth	*Opogona sacchari*	Lepidoptera		10
Citrus pock caterpillar	*Prays endocarpa*	Lepidoptera	na	
Avocado seed moth	*Stenoma catenifer*	Lepidoptera		19
Potato tuber moth	*Tecia solanivora*	Lepidoptera		1
Mormon Cricket	*Anabrus simplex*	Orthoptera		72
Southern Mole Cricket	*Scapteriscus borellii*	Orthoptera		4
Grasshopper	*Trimerotropis fratercula*	Orthoptera	na	
Pear Thrips	*Taeniothrips inconsequens*	Thysanoptera		2120
South African citrus thrips	*Scirtothrips aurantii*	Thysanoptera		2
California citrus thrips	*Scirtothrips citri*	Thysanoptera		2
Rice Thrips	*Stenchaetothrips biformis*	Thysanoptera		2
European Flower Thrips	*Frankliniella intonsa*	Thysanoptera		28
Western flower thrips	*Frankliniella occidentalis*	Thysanoptera		455
Melon Thrips	*Thrips palmi*	Thysanoptera		220
Chilli Thrips; Yellow Tea Thrips	*Scirtothrips dorsalis*	Thysanoptera		249
Thrips	*Haplothrips chinensis*	Thysanoptera	na	
Myoporum thrips	*Klambothrips myopori*	Thysanoptera	na	
Fruit tree spider mite	*Amphitetranychus viennensis*	Trombidiformes		7
Chile false red mite of grapes	*Brevipalpus chilensis*	Trombidiformes	na	
Litchi mite	*Eriophyes litchii*	Trombidiformes	na	
Cassava mite	*Mononychellus tanajoa*	Sarcoptiformes	na	
Fuchsia gall mite	*Aculops fuchsiae*	Trombidiformes	na	
Citrus brown mite	*Eutetranychus orientalis*	Trombidiformes		1
Tetranychid mite	*Oligonychus perditus*	Trombidiformes		1
Two-spotted Spider Mite	*Tetranychus evansi*	Trombidiformes		6
Pests identified to genus only				
Scarab beetles	Adoretus spp.	Coleoptera		
Longhorned Beetle	Anoplophora spp.	Coleoptera		
lily weevils	Brachycerus spp.	Coleoptera		
Weevils	Conotrachelus spp.	Coleoptera		
Bromeliad weevils	Metamasius spp.	Coleoptera		
Cerambycid Sawyer Beetle	Monochamus spp.	Coleoptera		
May-June beetles	Phyllophaga spp.	Coleoptera		
Popillia beetles	Popillia spp.	Coleoptera		
Wood-borers	Xyleborus spp.	Coleoptera		
Cerambycid Beetle	Xylotrechus spp.	Coleoptera		

Old world fruit flies	Ceratitis spp.	Diptera
Fruit flies	Pterandrus spp.	Diptera
Cuckoo wasps	Chrysis spp.	Hymenoptera
Cuckcoo bees	Coelioxys spp.	Hymenoptera
Noctuid Moth	Copitarsia spp.	Lepidoptera
Seed worms	Cydia spp.	Lepidoptera
Red Pine Shoot Moths	Dioryctria spp.	Lepidoptera
Tortricid moths	Proeulia spp.	Lepidoptera

Arthropod pest species not included in the five pest databases

Kanzawa spider mite	*Tetranychus kanzawai*	Trombidiformes
NA	*Tetranychus parakanzawai*	Trombidiformes
Bark beetle	*Crypturgus subcribrosus*	Coleoptera
Bark beetle	*Crypturgus hispidulus*	Coleoptera
Hairy spruce bark beetle	*Dryocoetes autographus*	Coleoptera
Bark beetle	*Dryocoetes hectographus*	Coleoptera
Engraver beetle	*Ips acuminatus*	Coleoptera
Bark beetle	*Orthotomicus suturalis*	Coleoptera
Striped Ambrosia Beetle	*Trypodendron lineatum*	Coleoptera
Fruit-tree pinhole borer	*Xyleborinus saxeseni*	Coleoptera
Ambrosia beetle	*Xyleborus affinis*	Coleoptera
Wireworm	*Hypnoidus bicolor*	Coleoptera
Yellow toadflax stem weevil	*Mecinus janthinus*	Coleoptera
Coffee berry borer	*Hypothenemus hampei*	Coleoptera
Hessian fly	*Mayetiola destructor*	Diptera
African fig fly	*Zaprionus indianus*	Diptera
Blueberry gall midge	*Dasineura oxycoccana*	Diptera
Glasshouse Striped Sciarid	*Bradysia ocellaris*	Diptera
Citrus mealybug	*Planococcus citri*	Hemiptera
Solenopsis mealybug	*Phenacoccus solenopsis*	Hemiptera
Apple mealybug	*Phenacoccus aceris*	Hemiptera
Matsumoto mealybug	*Crisicoccus matsumotoi*	Hemiptera
Cyanotis scale	*Aspidiotus excises*	Hemiptera
Mottled arum aphid	*Neomyzus circumflexus*	Hemiptera
Leaf curl plum aphid	*Brachycaudus helichrysi*	Hemiptera
Cabbage aphid	*Brevicoryne brassicae*	Hemiptera
Asian sowthistle aphid	*Hyperomyzus carduellinus*	Hemiptera
Aphid	*Toxoptera aurantii*	Hemiptera
Bronze bug	*Thaumastocoris peregrinus*	Hemiptera
Grapewine leafminer	*Antispila hydrangaeella*	Lepidoptera
Leaf worm	*Copitarsia decolora*	Lepidoptera
NA	*Lymantria sinica*	Lepidoptera
Beet armyworm	*Spodoptera exigua*	Lepidoptera
Paddy armyworm	*Spodoptera mauritia*	Lepidoptera
Onion thrips	*Thrips tabaci*	Thysanoptera
Black flower thrips	*Haplothrips reuteri*	Thysanoptera

(na = not available)

Number of BINs	BIN code
1	ACB6359
1	AAZ0928
1	AAP5743
1	AAE6821
1	AAO3421
1	AAL5975
1	AAL6427
1	AAC5728
1	ACD3954
1	AAJ8840
1	ACO5038
1	AAF8687
1	AAL7691
1	ABA6367
1	ACG1093
1	ABX2319
1	AAA7915
1	AAA5673
1	AAE7566
1	AAF8473
1	AAD4999
1	ABA9101
1	ACD6019
1	ACD6123
1	AAU7332
1	AAO2348
1	AAK3643
1	AAM9608
1	AAW8984
1	AAC0432
1	AAO1465
1	ACI2251
1	ACD8272
1	AAX4387
1	AAE2308
1	ACS9826
1	AAX4767
1	AAA9568
1	ACA8527
1	ACD2221
1	ACH5975
1	AAM7726
1	ABW3885
1	ACW0577
1	AAY3807

	1	ACB4636							
	1	AAN5824							
	1	AAF0418							
	1	AAL1083							
	1	AAG5234							
	1	AAJ3387							
	1	AAD7174							
	1	ACB4168							
	1	ACB5975							
	1	AAG5235							
	1	AAK2322							
	1	AAF8461							
	1	AAO2965							
	1	AAH8082							
	1	AAJ8909							
	1	AAD0158							
	1	ACB4804							
	1	AAC6184							
	2	ACB5345	AAJ6706						
	2	ABW4612	ACB5997						
	2	AAN9744	ACF4621						
	2	AAO4877	ABW2162						
	2	ABW1985	ABW1986						
	2	AAN6210	ABW2856						
	2	AAC3388	AAX4737						
	2	ABA0664	ACE2325						
	2	ACB5595	ACS6319						
	2	ABW2564	ABW2565						
	3	AAJ2718	ACF1042	ACE5628					
	3	ACD4149	ACD4150	ACD4151					
	3	AAG5209	ABW1289	ACK9843					
	3	AAB5012	AAB5013	AAB5014					
	3	AAK5928	AAO0694	ABW1460					
	3	AAM7754	ACB5750	ACB5751					
	4	AAD6254	AAD6255	ACD0626	ACN4884				
	4	AAN0875	AAN5825	ACF2995	ACF4025				
	4	ACG7166	ACG7185	ACG7186	ACG7187				
	4	AAV2624	ABY3924	ABZ6273	ABZ6274				
	5	AAL7152	AAW6793	ACB4584	ACD4027	ACF0641			
	6	ABW2361	ABW2362	ABX9120	ACX3534	ACX3535	ACX3890		
	13	AAZ7568	ACD4578	ACD4579	ACD4577	ACD4580	ACD7203	ACD7204	ACD7205
na									
na									
na									
na									
na									
na									

na
na

2

2

1

1
1

1

1

1

1
2

1
2
1
1
1

1
1
1

na

2

1

2

Draft

1 AAE5912
1 AAJ2068
1 AAC0699
1 AAF3739
1 AAA2296
1 AAC1495
1 AAD3172
1 AAA5439
1 AAA2296
1 AAB9956
1 ACD2253
1 ACP5553
1 ACP5553
1 ACP5553
1 AAB2814
1 ACI0768
1 AAB6024
1 AAC2003
1 AAC2499
1 AAD8670
1 ABA6469
1 AAC9720
1 AAL1148
1 AAD5604

	1	ACH4537							
	2	AAC9702	ACD5071						
	2	AAA5439	ACP5553						
	2	AAA2296	ACP5553						
	2	AAA3297	AAA3298						
	2	AAF6797	ABU6382						
	2	AAJ2102	ACD2707						
	2	AAD5604	AAD5605						
	2	AAE7386	AAE7387						
	3	AAB9711	AAB9712	ACV6711					
	4	AAB1381	AAC1495	AAP1683	ACP5553				
	5	AAA2296	ACP5553	ACQ2902	ACQ2903	ACS4697			
na									
	1								
	1	ACB6900							
	1	AAB7938							
	1	ACS3530							
	1	ABX5462							
	1	ACD4966							
	1	AAN4805							
	1	AAT8865							
	1	ACJ5808							
	1	AAF0501							
	1	AAJ2800							
	1	AAE8615							
	1	ACD2298							
	1	ACV6145							
	1	AAI6713							
	1	AAN9518							
	1	AAD7187							
	1	AAU6402							
	2	ACD6085	ACV7287						
	2	AAE4117	ACI1744						
	3	AAK5312	AAM9563	ACV6203					
	4	AAA2669	AAA2670	AAA2671	AAA2672				
	16	AAA4495	AAG4846	AAM1243	AAM1244	AAM1245	AAM1246	AAM1247	AAM1248
na									
na									
na									
na									
na									

1

na

1

1

2

1

1

1
4

1

2

1 ACQ5023
1 AAB8469
1 AAF8342
2 AAY0230 ACD3968
2 AAX4442 ACM6242
2 ACB7411 AAZ8297

1
1 AAA6716
1 AAA5320
1 AAB4903
1 AAA3364
1 AAB5839
1 AAC2750
1 AAA2955

1 AAB4345
1 AAA7177
1 AAC0302
1 ACB4958
1 AAA3301
1 ABX5883
1 AAA1517
1 AAB3384
1 AAA4000
1 AAA7282
1 AAA3532
1 AAC0640
1 AAJ4608
1 AAB6845
1 AAB6845
1 AAC8071
1 AAB4478
1 ACR7868
1 AAM4530
1 AAD0545
1 AAC5227
1 AAB0679
1 AAB4418
1 AAC5182
1 AAD8039
1 AAB9236
1 AAB0379
1 ABZ5815
1 AAA2435 AAA2436
1 AAK4075
1 AAE7333
1 ACM4472
1 ACS3950
1 AAA5528 ACD7806
1 ACD8827
1 AAC4957
1 AAA2052
1 AAA5537
1 AAA2052
1 AAD1618
1 AAA6548
1 AAA4130
1 ACD7464
1 AAA3963
1 AAE5045
1 ACE3275
1 AAA2654

1	AAA4433					
1	AAC8302					
1	ACF1624					
1	AAL3637					
1	AAH4802					
1	AAX1708					
1	AAC0387					
1	AAB9396					
1	AAB0552					
1	AAD1611					
1	AAA6521					
1	ACE4947					
1	AAA8626					
1	AAF3338					
1	AAC4688					
1	AAE7729					
1	AAC2506					
1	AAJ8033					
1	AAA7740					
2	AAL6887	ACS2942				
2	AAB0523	ACS0456				
2	AAA5223	ACS4718				
2	AAA3848	AAA3849				
2	ACQ6703	ACQ6704				
2	AAK9162	ACD4054				
2	AAB0845	ACS1452				
2	AAK7015	ACF2087				
2	AAA0476	AAN6936				
2	AAA2999	AAA3000				
2	AAA5192	ABY7901				
2	AAA4532	ACE4783				
2	ABV0114	ACH4173				
3	AAD8062	ABA2177	ABY6932			
3	AAB0666	AAL8547	ACV6760			
3	AAC8071	AAD8750	AAO4234			
3	AAA5482	ACE9385	ACE9387			
3	AAD6030	AAD6031	ACA1681			
4	AAA0257	AAB2755	AAB2756	AAD9057		
6	AAE7334	AAO2620	ABA8540	ACH6349	ACV6559	ACV8800

1

1

3

4

1								
1								
5								
1								
3	AAJ2390	ACA6391	ACA6392					
2								
1	ACC0651							
2	AAI0797	AAI0798						
2	AAI0768	AAI0769						
2	AAT9983	ACI0102						
3	AAF6737	AAN4977	ACD6098					
4	AAB8717	AAM5263	ACB4865	ACX8955				
4	AAE7913	AAM8085	AAN2747	ACI0120				
12	AAC9747	AAC9748	AAC9749	AAC9750	AAC9751	ACQ0434	ACQ0435	ACQ4218
1	ACQ0009							
2	ACB5670	ACB5671						

ACD7206 ACD7474 ACD7547 ACE8205 ACF4217

AAT8875 ACB7300 ACD4214 ACD5051 ACN1674 ACR3284 ACV2709 ACV2710

ACV6509 ACV6510 ACV6511 ACV7644