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ORIGINAL PAPER

Exploring the role of wood waste landfills in early detection of non-native wood-boring beetles

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Abstract Non-native wood-boring beetles (Coleoptera) represent one of the most commonly intercepted groups of insects at ports worldwide. The development of early detection methods is a crucial step when implementing rapid response programs so that non-native wood-boring beetles can be quickly detected and a timely action plan can be produced. However, due to the limited resources often available for early detection, it is important to identify the best locations where to concentrate surveillance efforts. The aim of this study was to investigate the role of wood waste landfills in the early detection of non-native wood-boring beetles. From June to September 2013, insects were collected in multi-funnel traps baited with a multi-lure blend (α-pinene, ethanol, ipsdienol, ipsenol, and methyl-butenol) at the main port and a nearby wood waste landfill in 12 Italian towns. Overall, 74 species of wood-boring beetles (Buprestidae, Cerambycidae, and Scolytinae) were trapped, among which eight were non-native to Italy. We found that species richness and species abundance of both non-native and native beetles were significantly higher in the wood waste landfill than in the ports. However, the non-native and native communities were similar in the two environments. The main conclusion emerging from this study is that wood waste landfills, given their similarity with ports of entry, should be considered when surveying for non-native wood-boring beetles. Therefore, within the framework of creating long-term monitoring programs that include both coastal and continental areas, both ports and wood waste landfills should be monitored to improve the probability for early detection of non-native species.

Keywords Bark beetles · Invasive species · Jewel beetles · Longhorn beetles · Surveillance · Wood packaging materials

Key message

- Early detection efforts increase the probability of trapping non-native species but require costly investments.
- Identification of trapping sites that enhance the efficiency of early detection is important when allocating limited resources.
- This study demonstrates that wood waste landfills could be considered as useful sites for trapping non-native wood-boring beetles in continental areas and thereby complement surveillance efforts carried out in ports located in coastal areas.

Introduction

Non-native wood-boring beetles are considered among the most dangerous forest pests worldwide with established populations of new species being reported nearly every year somewhere in the world (LaBonte et al. 2005; Work

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et al. 2005; Haack 2006; Kirkendall and Faccoli 2010). The rate of establishment of non-native wood-boring beetles is also increasing worldwide (Brockerhoff et al. 2014). For example, although wood-boring beetles represented only 11 % of the detected non-native species in the United States between 1800 and 1930, they represented 56 % of the new detections during 1980–2006 (Aukema et al. 2010). This pattern likely reflects the dramatic increase in volume of containerized shipping worldwide (Cullinane and Khanna 2000), which often entails the use of solid wood packaging materials such as crating, dunnage, and pallets. These materials represent the most common pathway of introduction for wood-boring beetles (Kenis et al. 2007; Zahid et al. 2008; Colunga-Garcia et al. 2009; DAISIE 2009) given that these insects develop under bark or inside wood where they can easily escape detection by inspectors and that the wood substrate itself protects these borers during transport (Haack 2001; Brockerhoff et al. 2006a; McCullough et al. 2006). Moreover, given that wood packaging materials are often manufactured from untreated, low-grade timber with residual bark (Haack and Petrice 2009), they can be infested by a wide variety of wood-boring beetles (Allen and Humble 2002; Evans 2007). In recognition of the threat posed by untreated wood packaging materials, an international standard (ISPM 15) was first approved in 2002 and was revised in 2013 (International Plant Protection Convention (IPPC) 2013). ISPM 15 details how wood packaging materials should be treated (e.g., minimum 56 °C core temperature for 30 min for conventional heat treatment) prior to their use in international trade (Keiran and Allen 2004; Evans 2007). Although ISPM 15 has reduced the rate of infested wood packaging material, some treatments may be improperly applied, either knowingly or because of faulty equipment or facilities (Haack and Petrice 2009), and thus, live borers are still found occasionally in treated wood packaging, indicating that the risk of biological invasions through the wood pathway still exists (Haack et al. 2014).

Maritime ports and airports, where goods arrive from all over the world, are the primary points of entry for non-native species (Haack 2001, 2006; Brockerhoff et al. 2006b; McCullough et al. 2006; Wylie et al. 2008). When a non-native species arrives at a port of entry, it can potentially become established and spread either naturally into the surrounding areas (Bashford 2008; Rassati et al. 2014a, b) or—if dispersal is human mediated—to disjunct sites located dozens or even hundreds kilometers from the original point of establishment (Piel et al. 2008; Hulme 2009; Colunga-Garcia et al. 2013). Because of the limited resources typically available for surveillance of non-native species and the high number of sites potentially exposed to non-native introductions (Colunga-Garcia et al. 2013), identification of the sites most vulnerable to establishment is important when designing surveillance efforts (Epanchin-Niell et al. 2014). Previous studies suggested, for instance, that timber importers, botanic gardens (Self and Kay 2005), or ornamental nurseries (Liebhold et al. 2012) are among the most at risk sites for pest introductions and therefore, should be considered when designing monitoring efforts for non-native pests. In the case of wood-boring beetles, much of the wood packaging materials associated with imports often goes to wood waste landfills (Buehlmann et al. 2009), and therefore, such sites may play a key role in the establishment of non-native species. It is important to recognize that only a small percentage of containers arriving through international trade is opened and inspected at the original port of entry (Haack 2001; Stanaway et al. 2001), with most commodities being instead transported directly to industrial or commercial areas (Colunga-Garcia et al. 2009). In such cases, the associated wood packaging materials are often discarded and sent to companies authorized to recycle or destroy the wood (Buehlmann et al. 2009). Although wood waste landfills have been already recognized as a potential site for establishment of wood-infesting insects (Auclair et al. 2005; Rabaglia et al. 2008), we are not aware of any studies that have empirically investigated the effectiveness of trapping non-native wood-boring beetles in such sites.

The purpose of this study was to investigate the potential role of wood waste landfills, given that they serve as endpoints for wood packaging materials, in the early detection of non-native wood-boring beetles (Buprestidae, Cerambycidae, and Scolytinae). As wood waste landfills can receive wood packaging materials from many commercial routes, and often the wood packaging materials reside at such sites for longer periods of time than in the ports, we expected the wood waste landfills to have a relatively high species richness and species abundance of wood-boring beetles attesting to their value as monitoring sites, especially for early detection efforts in continental areas away from coastal ports.

Materials and methods

Selection of the experimental sites

The survey was carried out in 12 coastal towns located along the Italian peninsula and in the main Italian islands of Sardinia and Sicily in 2013 (Table 1). In each town, the port and the main wood waste landfill closest to the port were monitored. The selected ports were those that import large amount of solid commodities from every part of the world (Assoporti 2014) and therefore, should also receive large amounts of associated wood packaging materials. We selected those wood waste landfill sites that were

Table 1 Port name, geographic coordinates, and distance between the port and the nearby selected wood waste landfill (WWL) (km) for each of the 12 selected Italian towns where sampling occurred in 2013

Town	Port	Lat.	Long.	Distance between port and paired WWL
Ancona	Ancona	43°37′	13°30′	19.86
Cagliari	Cagliari	39°15′	09°05′	6.10
Genova	Genova	44°24′	08°52′	2.87
Gorizia	Monfalcone	45°47′	13°32′	11.52
Napoli	Napoli	40°50′	14°16′	14.78
Palermo	Palermo	38°08′	13°21′	5.51
Ravenna	Ravenna	44°28′	12°15′	4.88
Salerno	Salerno	40°40′	14°44′	9.88
Sassari	Porto Torres	40°53′	08°39′	3.23
Trieste	Trieste	45°39′	13°15′	5.19
Udine	Porto Nogaro	45°47′	13°13′	4.58
Venezia	Marghera	45°27′	12°15′	2.71

authorized to destroy, recycle, and treat any kind of wood products. The distance between the selected ports and their paired wood waste landfill ranged from about 3–20 km (Table 1). Both ports and wood waste landfills were surrounded by a heterogeneous landscape, composed of mosaics of urban areas, green spaces, crop fields, and different types of forests.

Trapping design and lures

Six 12-unit, black funnel traps (Econex, Murcia, Spain) were set up in each of the 12 towns, with three traps placed inside the port and three traps in the nearby wood waste landfill. The commercial "dry-version" of the trap was used. A distance of at least 30 m was kept between traps. The tops of the traps were hung about 2 m off the ground, using suitable supports such as building structures, wire fences, and metal girders. All traps were in relatively open areas where insects could approach from several directions.

Traps were baited with a multi-lure blend that was previously tested and found to be attractive to a wide variety of wood-boring beetles (Rassati et al. 2014a) and composed of (−)α-pinene (ultra-high release, release rate of 2 g day^{-1}; 90-day field-life at 20 °C), ethanol (release rate of 0.3 mg day^{-1}; 90-day field-life at 25 °C), ipsenol (+50/−50; release rate of 0.4 mg day^{-1}; 90-day field-life at 20 °C), ipsdienol (release rate 0.4 mg day^{-1}; 90-day field-life at 20 °C), and 2-methyl-3-buten-2-ol (release rate of 11 mg day^{-1}; 90-day field-life at 20 °C), all provided by Contech Enterprises Inc. (Victoria, BC, Canada). The collector cup of each trap was sprayed with an insecticide (Decis, Bayer Crop Science, Triangle Park, NC, USA) to quickly kill the trapped insects. The lure dispensers were changed after two months from the beginning of the monitoring, and the insecticide was renewed at each trap check.

Trapping lasted for about 14 weeks during June through September 2013, with a number of trap checks varying from 2 to 8 (mean $n = 5.8$), depending on local restrictions regarding access to the ports and wood waste landfills. Despite some beetles, especially some early-season ambrosia beetles, may have been missed, we assumed that the trapped species provide a clear indication of the role that the tested sites may play in the early detection. Moreover, although the number of trap checks was different, the traps were exposed for the same period of time (mean ± SE = 96.3 days ± 4.53). Trapped wood-boring beetles (Buprestidae, Cerambycidae, and Scolytinae) were stored in alcohol until morphological identification. When needed, DNA extraction was conducted following a standard salting out protocol (Patwary et al. 1994). The barcode region of the mitochondrial gene cytochrome oxidase I was then amplified using universal primers (Folmer et al. 1994), and the resulting sequences were entered in the Bold System database (Ratnasingham and Hebert 2007). Once identified, beetles were then classified either as native or non-native species, including in the latter group both species newly intercepted or already established in Italy (Balachowsky 1949; Wood and Bright 1992; Curletti 1994; Bense 1995; Pfeffer 1995; Jendek 2006; Kubán 2006; Kirkendall and Faccoli 2010; Löbl and Smetana 2010; Knížek 2011).

Data analysis

To account for the differences in trapping frequency and the variability due to the longer intervals between less-frequent trap checks, we used a general linear mixed-effects model to evaluate the effect of the time between trap checks on the mean number of species or abundance per trap. The total number of non-native and native species (i.e., richness) and individuals (i.e., abundance), obtained after pooling together the collection data for all traps per site for the entire season, was the response variables. Then, we calculated the model residuals, and we used them as a response variable to test the effect of trap position (categorical variable: port vs. wood waste landfill). The new response variable did not depend on the duration of the trapping period. The model included the site as a random factor to account for the spatial dependence of the sampling. The model was fitted using the 'lme' function in the package nlme (Pinheiro et al. 2013) for R version 2.15.1 (R Development Core Team 2013). The non-native and native species abundance was log-transformed to improve linearity. The model included site as a random factor to account for spatial dependence of the trapping. All variables were reported as mean ± standard error of the mean

(SEM). The detection frequency of non-native species with enough catch events (presence/absence) recorded in the two different environments (port and wood waste landfill) was compared with a Fisher's exact test. Finally, the Simpson's Similarity Index (Magurran and McGill 2010) was used to test for the similarity between species recorded in ports and wood waste landfills, where a value close to one indicates very similar insect communities in the two sampled environments. Differences in similarity between non-native and native species were tested by one-way ANOVA.

Results

Trapped beetles

During the survey, in total, 74 species of wood-boring beetles were trapped (Tables 2, 3). The total number of beetles caught was 11,255, with Scolytinae representing the most diverse and abundant group (42 species and 10,987 individuals), followed by Cerambycidae (23 species, 244 individuals), and Buprestidae (nine species and 24 individuals). Although most species were native (66), five Scolytinae (*Ambrosiodmus rubricollis* (Eichhoff), *Cyrtogenius luteus* (Blandford), *Gnathotrichus materiarius* (Fitch), *Hypothenemus eruditus* Westwood, *Xylosandrus germanus* (Blandford)), and three Cerambycidae (*Cordylomera spinicornis* (Fabricius), *Neoclytus acuminatus* (Fabricius), *Xylotrechus stebbingi* Gahan) were non-natives. Most of them were already known to be established both in Italy and other European countries. The cerambycid *C. spinicornis* had been collected in earlier surveys (Cola 1971; Rassati et al. 2014b) but it is still not considered to be established in Italy.

Among the non-native species, *C. luteus* was the most abundant scolytid with 66 individuals collected, while *X. stebbingi* (56 individuals) was the most commonly collected cerambycid. Three species were represented by only one individual each (*A. rubricollis*, *X. germanus*, and *N. acuminatus*). Among native species, *Orthotomicus erosus* (Wollaston) (6,478 individuals) and *Ips sexdentatus* (Borner) (1,741 individuals) were the two most commonly collected native Scolytinae, while *Acanthocinus griseus* (Fabricius) and *Buprestis novemmaculata* L. were the most abundant native Cerambycidae and Buprestidae, with 47 and nine individuals, respectively.

Ports versus wood waste landfills

For non-native wood-boring beetles, we found significant differences both in species richness and abundance between the beetles collected at the ports and wood waste landfills. In particular, the mean number of non-native species trapped per site in wood waste landfills (1.50 ± 0.33) was significantly higher than in ports (0.75 ± 0.27) (GLMM, $P < 0.05$, Fig. 1a). The same trend was found considering the mean number of individuals trapped per site (9.3 ± 5.66 at wood waste landfills vs 2.08 ± 1.03 at ports, GLMM, $P < 0.05$, Fig. 1b). Among non-native species, one species was trapped exclusively in ports, two were trapped exclusively in wood waste landfills, and five were found in both environments (Tables 2, 3). Comparing the detection frequency, we found a significant difference only for the non-native scolytid *G. materiarius*, which was more frequently trapped in wood waste landfills than in ports (Table 2).

For native wood-boring beetles, we found significant differences in both species richness and abundance between ports and wood waste landfills. In particular, the mean number of native species trapped per site in wood waste landfills (12.6 ± 1.55) was significantly higher than in ports (9.6 ± 1.65) (GLMM, $P < 0.05$, Fig. 1c). The same trend was found considering the mean number of native individuals trapped per site (626.81 ± 174.31 vs. 233 ± 80.94, respectively, GLMM, $P < 0.05$, Fig. 1d). Among native species, 18 species were trapped exclusively in ports, 17 were trapped exclusively in wood waste landfills, and 31 were found in both environments. Comparing the detection frequency of native species, we found a significant difference for eight species, among which seven were more frequently trapped in wood waste landfills (the Scolytinae *Crypturgus cinereus* (Herbst), *Crypturgus mediterraneus* Eichhoff, *Crypturgus numidicus* Ferrari, *Ips sexdentatus* (Borner), *Ips typographus* (L.), *Xyleborus monographus* (Fabricius), and the cerambycid *A. griseus* (Fabricius)), and one (the scolytid *Ips acuminatus* (Gyllenhall)) was more frequently trapped in ports (Tables 2, 3). The Simpson's Similarity Index for non-native species between the ports and the wood waste landfills (0.83) was similar to that of native species (0.68) ($P = 0.34$, $n = 12$).

Discussion

The early detection of non-native species is basic to implementation of rapid response systems, and development of effective eradication and suppression protocols for invasive pests (Pluess et al. 2012). However, one of the first steps when developing early detection programs is to identify sites or habitats that are at high-risk of invasion and then to concentrate the surveillance efforts at these areas, including both coastal and continental sites (Epanchin-Niell et al. 2014). The present study suggested that wood waste landfills, as with ports, could be considered as useful sites for trapping non-native wood-boring beetles. Using baited traps to survey

Table 2 Abundance (total number of individuals trapped during the season), detection frequency (%), results of the Fisher exact test, and native distribution for each Scolytinae trapped in the 2013 survey comparing ports and wood waste landfills (WWL) at 12 paired sites in Italy ($n = 70^{+}$)

	Port	WWL	Port (%)	WWL (%)	*P* value	Native to
Scolytinae						
Ambrosiodmus rubricollis (Eichhoff)[a]	0	1	0	1.4	–	A
Anisandrus dispar (Fabricius)	1	0	1.4	0	–	A, E
Carphoborus perrisi (Chapuis)	5	9	7.1	7.1	1	A, E, N
Cyrtogenius luteus (Blandford)[a]	15	51	8.5	10	1	A
Cryphalus piceae (Ratzeburg)	4	4	5.7	4.2	1	A, E, N
Crypturgus cinereus (Herbst)	3	25	4.2	22.8	*	E
Crypturgus cribrellus Reitter	2	–	2.8	0	0.33	E
Crypturgus mediterraneus Eichhoff	8	43	10	24.2	*	A, E, N
Crypturgus numidicus Ferrari	3	17	4.2	15.7	*	A, E, N
Crypturgus pusillus (Gyllenhall)	8	3	4.2	2.8	1	A, E
Gnathotrichus materiarius (Fitch)[a]	–	8	0	8.5	*	NA
Hylastes attenuatus Erichson	1	2	1.4	1.4	–	A, E
Hylurgus ligniperda (Fabricius)	81	569	51.4	65.7	0.15	A, E, N
Hylurgus micklitzi Wachtl	249	830	50	60	0.33	A, E, N
Hypoborus ficus Erichson	8	10	4.2	8.5	0.34	A, E, N
Hypothenemus eruditus Westwood[a]	–	2	0	2.8	–	SA?
Ips acuminatus (Gyllenhall)	8	–	5.7	0	*	A, E
Ips amitinus (Eichhoff)	1	–	1.4	0	–	A, E
Ips sexdentatus (Borner)	888	853	48.5	70	*	A, E
Ips typographus (Linnaeus)	85	196	10	27.1	*	A, E, N
Liparthrum mori (Aubé)	1	–	1.4	0	–	A, E
Orthotomicus erosus (Wollaston)	1,405	5,073	80	88.5	0.51	A, E, N
Orthotomicus laricis (Fabricius)	3	2	2.8	1.4	–	A, E, N
Phloeotribus cristatus (Fauvel)	1	–	1.4	0	–	A, E, N
Pityogenes calcaratus (Eichhoff)	1	–	1.4	0	–	A, E
Pityogenes chalcographus (Linnaeus)	3	1	4.2	1.4	0.48	A, E
Pityokteines spinidens (Reitter)	2	3	1.4	2.8	–	A, E
Pityokteines vorontzowi (Jacobson)	4	7	4.2	2.8	1	A, E
Pteleobius kraatzii (Eichhoff)	–	2	0	2.8	–	A, E, N
Scolytus amygdali Guerin	–	1	0	1.4	–	A, E, N
Scolytus multistriatus (Marsham)	16	9	5.7	5.7	1	A, E
Scolytus rugulosus (Muller)	1	3	1.4	2.8	–	A, E, N
Taphrorychus alni Pfeffer	–	1	0	1.4	–	E
Trypodendron lineatum (Olivier)	4	3	2.8	2.8	–	A, E, N
Trypophloeus binodulus Ratzeburg	1	–	1.4	0	–	A, E, N
Triotemnus ulianai (Gatti & Pennacchio)	–	2	0	2.8	–	E
Xyleborinus saxesenii (Ratzeburg)	129	294	48.5	62.8	0.14	A, E, N
Xyleborus eurygraphus (Fabricius)	1	11	1.4	7.1	0.08	A, E, N
Xyleborus monographus (Fabricius)	–	5	0	5.7	*	A, E, N
Xylocleptes bispinus (Duftschmis)	–	3	0	2.8	–	A, E, N
Xylocleptes biuncus Reitter	1	–	1.4	0	–	A, E, N
Xylosandrus germanus (Blandford)[a]	–	1	0	1.4	–	A

+ Total number of trap checks performed in 2013 at all 24 trapping locations (12 ports and 12 landfills)

A Asia, *E* Europe, *N* North Africa, *NA* North America, *SA* South America

* *P* value < 0.05

[a] Indicates non-native species

Table 3 Abundance (total number of individuals trapped during the season), detection frequency (%), results of the Fisher exact test, and native distribution for each Cerambycidae and Buprestidae trapped in the 2013 survey comparing ports and wood waste landfills (WWL) at 12 paired sites in Italy ($n = 70^{+}$)

	Port	WWL	Port (%)	WWL (%)	*P* value	Native to
Cerambycidae						
Acanthocinus griseus (Fabricius)	13	34	11.4	22.8	*	A, E
Aegomorphus clavipes (Schrank)	–	1	0	1.4	–	A, E, N
Arhopalus ferus (Mulsant)	–	1	0	1.4	–	A, E, N
Arhopalus rusticus (Linnaeus)	–	4	0	4.2	0.1	A, E, N
Arhopalus syriacus (Reitter)	–	3	0	4.2	0.1	A, E, N
Aromia moschata (Linnaeus)	2	–	2.8	0	–	A, E
Asemum striatum (Linnaeus)	–	1	0	1.4	–	A, E
Callimus angulatus (Schrank)	–	2	0	1.4	–	A, E, N
Chlorophorus glabromaculatus Goeze	3	5	4.2	7.1	0.61	E
Chlorophorus varius (Müller)	8	–	4.2	0	0.1	A, E
Cordylomera spinicornis (Fabricius)[a]	2	–	2.8	0	0.33	WA
Hylotrupes bajulus (Linnaeus)	9	10	7.1	11.4	0.43	A, E, N
Leiopus nebulosus (Linnaeus)	–	1	0	1.4	–	A, E
Monochamus galloprovincialis (Olivier)	13	7	5.7	7.1	1	A, E, N
Neoclytus acuminatus (Fabricius)[a]	–	1	0	1.4	–	SCA
Niphona picticornis Mulsant	–	1	0	1.4	–	A, E, N
Parmena solieri Mulsant	3	–	2.8	0	–	E
Penichroa fasciata (Stephens)	3	1	1.4	1.4	–	A, E, N
Rusticoclytus rusticus Linnaeus	1	–	1.4	0	–	A, E, N
Spondylis buprestoides (Linnaeus)	28	7	7.1	4.2	0.61	A, E, N
Stictoleptura cordigera (Fuessly)	1	2	1.4	2.8	–	A, E, N
Trichoferus fasciculatus (Faldermann)	6	15	2.8	7.1	0.28	A, E, N
Xylotrechus stebbingi Gahan[a]	8	48	11.4	20	0.13	A
Buprestidae						
Agrilus viridicaerulans Marseul	–	1	0	1.4	–	E, N
Buprestis haemorrhoidalis Herbst	–	4	0	5.7	0.1	A, E, N
Buprestis novemmaculata Linnaeus	2	7	2.8	7.1	0.28	A, E, N
Buprestis octoguttata Linnaeus	1	–	1.4	0	–	A, E
Eurythyrea micans (Fabricius)	1	–	1.4	0	–	E, N
Melanophila cuspidata (Klug)	1	–	1.4	0	–	A, E, N
Palmar festiva (Linnaeus)	–	3	0	2.8	–	E, N
Phaenops cyaneus (Fabricius)	1	–	1.4	0	–	A, E, N
Phaenops formaneki Jacobson	3	–	1.4	0	–	A, E

+ Total number of trap checks performed in 2013 at all 24 trapping locations (12 ports and 12 landfills)

A Asia, *E* Europe, *N* North Africa, *SCA* South-Central America, *WA* West Africa

* *P* value < 0.05

[a] Indicates non-native species

such sites could either potentially increase the probability of locating new non-native species or add information on the distribution of already established ones, therefore allowing for a timely response to implement eradication efforts or destroy infested materials.

We found that non-native species richness was higher in wood waste landfills than in ports, even though the composition of the wood-boring beetle communities was similar in the two environments. Ports, which receive large amounts of commodities associated with wood packaging materials, were previously identified as the most high-risk sites for non-native species introductions (Brockerhoff et al. 2006b; Bashford 2008; Rabaglia et al. 2008; Wylie et al. 2008; Rassati et al. 2014a). However, despite the integrated use of trapping protocols and traditional inspection methods that strongly increase the probability of detecting non-native species soon after arrival at the ports (Brockerhoff et al. 2006b; Rabaglia et al. 2008; Rassati et al. 2014a), some individuals may escape detection, become established, and spread naturally in the surrounding areas or at further distances when their dispersal is human mediated (Piel et al. 2008; Colunga-Garcia et al. 2013). For this reason, the identification of hotspots for invasion, such as sites handling significant volumes of timber and wood packaging materials, has been highlighted as a priority to enhance the efficacy of early detection programs (Self and Kay 2005; Ostrauskas and Tamutis 2012; Colunga-Garcia et al. 2013). Our results suggested

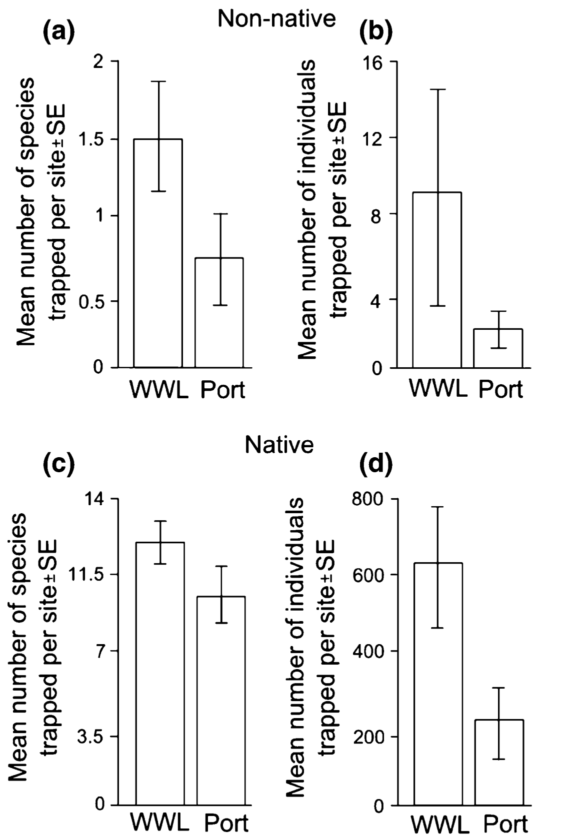

Fig. 1 Mean number of species and individuals (+SE) trapped per site in wood waste landfills (WWL) and maritime ports in 12 Italian towns over an approximate 14-week trapping period in 2013 (see text for details)

that wood waste landfills, which can be considered as the last step in the life cycle of wood packaging materials (Buehlmann et al. 2009), can serve as high-risk sites for non-native wood-boring beetle invasion. In fact, despite that all the non-native species trapped in this trial were already established in Italy (Kirkendall and Faccoli 2010), they can provide useful indication of the suitability of a given site to be invaded, especially considering that every year new individuals can arrive in areas where the species are not yet present. For example, the non-native scolytid *C. luteus*, which has been reported in the Veneto (Faccoli et al. 2012) and Friuli Venezia Giulia (Rassati et al. 2014b) regions of Italy until 2012, was trapped simultaneously at port and wood waste landfill in the Emilia Romagna region during this trial, underlining the potential role of both habitats in non-native species invasion. The deployment of traps baited with generic lures inside wood waste landfills should enhance detection of non-native wood-boring beetles and thereby act as an early warning system to trigger eradication programs or other measures to contain the spread of non-native species. Moreover, as broadleaf forest's surrounding points of entry have been already highlighted to be crucial sites for the interception of non-native species (Rassati et al. 2014b), the simultaneous use of baited traps both in wood waste landfills and surrounding broadleaf stands could increase the possibility of trapping non-native wood-boring beetles.

We found that non-native species abundance was significantly higher in wood waste landfills than in ports. The amount of wood packaging materials present in wood waste landfills can be stored for longer periods of time than in ports, increasing the probability of non-native species emerging and dispersing from wood waste landfills. In ports, the type of woody materials, their amount, and their storage location are often unpredictable, which affects the possibility of establishing effective survey protocols and thus the probability to detect non-native species (Rassati et al. 2014a). Typically, the number of sites involved in processing, destroying, recycling, or treating wood packaging materials is high within most countries and therefore, is important information to use when selecting survey sites. In this regard, previous studies indicated that, as a general rule, higher amounts of imported commodities in a given area increase the probability of non-native species introduction, and this has been demonstrated at both continental (Mack et al. 2000; Haack 2001; Marini et al. 2011; Huang et al. 2012; Liebhold et al. 2013) and port scale (Rassati et al. 2014b). We suggest that this rule should be applied to wood waste landfills, adjusting for variation in the volume of handled wood packaging materials. A better understanding of how such wood is managed and treated at different wood waste landfills will enhance the decision process about where surveillance efforts should be focused. Another important issue to consider is the timeliness of trap collections at ports and wood waste landfills. On the one hand, given that landfill sites are usually located in continental areas, the capture of non-native species often provides little information as to where the non-native organism first entered the country, which is useful when developing eradication strategies. On the other hand, trapping at landfill sites can provide useful data on the geographical range of newly or recently arrived non-native species, which is useful when forming conservation and management strategies (Rassati et al. 2014b).

Lastly, we found that both native species richness and abundance were significantly higher in wood waste landfills than in ports, although the species compositions were similar in the two environments. Wood waste landfills are usually less isolated compared to ports, and thus, the surrounding landscape often has greater amounts of green space, such as forests and parks, which would favor the in-and-out exchange of native wood-boring beetles (Rassati et al. 2014b). Trapping of native species in such high-risk sites is, however, still poorly investigated. In fact, a subset of these native species may actually fly from the local vegetation surrounding the landfills or emerge from wood packaging materials that were associated with either national or international trade. In support of this idea is a study by Hu et al. (2013) that used molecular data to suggest that the native cerambycid *Monochamus alternatus* Hope, which vectors the pinewood nematode *Bursaphelenchus xylophilus* (Steiner & Buhrer), has expanded its range westward within mainland China, most likely through the inadvertent transport of infested wood packaging materials associated with trade within China. Similarly, considering that the Scolytinae *I. typographus* and *I. acuminatus* are typically distributed within continental areas of Italy, their presence also in coastal regions suggests that they were moved to the coast in infested logs or wood packaging materials. As further support, consider that *I. typographus* and *I. acuminatus* have been commonly intercepted on wood packaging materials associated with Italian imports to the U.S.A., which would have departed Italy from its coastal ports (Haack 2001; Haack and Rabaglia 2013). Future studies should focus on understanding if the native species that are most commonly trapped in high-risk sites are also the most prone to be transported in wood packaging materials and thereby constitute a pool of invaders that can be moved outside the country through international trade.

Despite the measures undertaken to prevent the arrival of non-native species, the potential of new introductions is still high and appears to be increasing along with the increasing volume of international cargo and the numbers of potential countries of origin (Aukema et al. 2010; Kirkendall and Faccoli 2010; Colunga-Garcia et al. 2013; Haack et al. 2014). Our results suggest that the use of baited traps in wood waste landfills, which provided detection results comparable to ports, would be an effective strategy to increase the efficiency of early detection of non-native species in continental areas far from the coast. The establishment of a monitoring network in both coastal and continental areas, with special attention to wood waste landfills, would likely increase the probability of detecting non-native wood-boring beetles compared with trapping primarily along coastal areas near ports. Moreover, given that countries often experience the highest invasion pressure in metropolitan and industrial areas, which represent the final destination of the imported goods (Colunga-Garcia et al. 2013), expanding our understanding on the dispersal and distribution of invasive species in urban and suburban areas represents the next major challenge to improving early detection strategies.

Author contribution statement

DR and EPT identified the beetles. DR and LM performed the statistical analyses. DR and EPT wrote the first draft of the manuscript. MF, LM, RAH, and AB contributed to the revision of the manuscript.

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