



Global movement of woodwasps (Hymenoptera: Siricidae) inferred from border interception records

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Abstract Global trade has accelerated the spread of wood-boring insects. Woodwasps (Hymenoptera: Siricidae) include several species that have established outside their native ranges, but their global translocation is not well documented. Despite several biases, port interception records can serve as indirect proxies of propagule pressure and can be used to quantify invasion pathways. Here, we use historical border interception records from the USA (1914–2020), Canada (1997–2019), and New Zealand (1950–2007) to infer global transport pathways and propagule pressure of siricids. We compiled 3054 interception

records, identifying dominant species, source biogeographical regions, and associated commodities. Interceptions were overwhelmingly linked to wood packaging materials, confirming this pathway as the principal vector of introduction. Most of the intercepted woodwasp species originated from the European and Asian Palearctic regions, indicating these areas as major historical sources of propagule pressure. However, increasing records from non-native regions suggest possible secondary introductions from previously established non-native populations (i.e., bridgehead regions). Despite frequent interceptions, only a subset of species has established, highlighting mismatches between propagule pressure and invasion success, likely mediated by ecological constraints on establishment such as host availability and climate. Our results demonstrate the value of

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long-term interception datasets for reconstructing invasion pathways, while emphasizing their limitations due to taxonomic uncertainty and sampling bias. Improving species identification and standardizing biosecurity data collection could enhance the use of interception records for invasion risk assessment and management.

Keywords ISPM 15 · Propagule pressure · Phytosanitary regulations · *Siricidae* · Solid wood packaging material · Bridgehead effect

Introduction

Non-native wood-boring insects increasingly threaten forest ecosystems, inflicting substantial ecological and economic damage. The expansion of global trade and travel increases the likelihood of introducing these pests to new regions (Banks et al. 2015; Brouckhoff et al. 2006b). These introductions often occur via the movement of contaminated imported goods or wood packaging materials. Understanding the pathways by which these woodborers are introduced is crucial for developing effective strategies to prevent future invasions and protect forest health. Historical data on border interceptions are valuable resources for characterizing pathways because of their often long time span and information associated with the interception records.

Woodboring insects belonging to the hymenopteran family *Siricidae* (commonly called woodwasps) are largely native to the northern hemisphere (128 species native to Asia, North America and Europe) (Schiff et al. 2012). Many woodwasp species have been accidentally transported worldwide in wood products and wood packaging material and are frequently intercepted at international ports of entry (Burnip et al. 2010). Several species have established outside their native range, such as *Sirex noctilio*, which has been introduced to North and South America, Australia, New Zealand, and South Africa (Slippers et al. 2015; Liebhold and Hajek 2019). More recently, North American species have been found in Europe and Asia, such as *Urocerus albicornis* (Háva and Holuša, 2019; Kuramitsu et al. 2019; López et al. 2012), and South America, such as *Sirex obesus* (Lantschner and Villacide 2025; Wilcken et al. 2025). Most invasions of wood borers

are facilitated by international trade because their larvae can go undetected within solid wood packaging materials such as pallets, crates, and dunnage (Brouckhoff et al. 2006a; Haack et al. 2014).

Some siricid species can cause considerable damage to forests, particularly when introduced to non-native ranges where natural enemies may be absent (Lantschner and Corley 2015). Studies carried out on a few harmful species, such as *S. noctilio*, provide baseline knowledge on the ecology of these insects (e.g., Slippers et al. 2012, 2015; Schiff et al. 2012). Adult females of siricids drill holes into host trees and deposit eggs. Usually, larvae are associated with symbiont phytotoxic fungi (e.g., *Amylostereum areolatum*), which provide food for the siricid larvae and weaken host trees. So far, only a few species of siricids have been proven to kill their hosts, such as *S. noctilio*; however, fungal associations and species ecology remain poorly known for many species. Siricid larvae are xylem borers, with some species specializing on coniferous hosts and others targeting deciduous trees. While siricids often attack stressed or declining trees, they can also cause significant mortality in seemingly healthy trees, especially in their introduced ranges. Additionally, environmental stressors like drought can promote increases in siricid populations to outbreak levels (Ismail and Mutanga 2010; Lantschner et al. 2019; Weigandt et al. 2023).

The continued growth of global trade makes preventing further introductions of harmful *Siricidae* species and other potentially invasive wood-boring insects a significant and ongoing biosecurity challenge (Chapman et al. 2017; Fenn-Moltu et al. 2023; Nardi et al. 2025). Effective biosecurity depends on information about arrivals of potential invaders and associated pathways. Border biosecurity inspection records can provide valuable insights into the frequency of arrival of these insects, but such data must be carefully interpreted because of inherent sampling biases (Brouckhoff et al. 2014). Despite these limitations, carefully-interpreted interception records can help identify which siricid species are being transported through international trade and provide crucial information about their geographic origins (Turner et al. 2021).

Here, we use historical records of species intercepted at ports in three major trading countries to characterize geographical patterns associated with

woodwasp interceptions at borders and their associations with commodities, and to highlight mismatches between propagule pressure and established populations. Finally, we identified strengths and weaknesses of using historical interception data and suggested best practices for compiling such data.

Methods

We analyzed biosecurity interception data for imported goods in the USA, Canada, and New Zealand. USA interception data were obtained from printed USDA reports (until 1984), from the USDA APHIS Agricultural Quarantine Activity System (AQAS) and PestID databases (until 2008), and from Worm et al. (2024). Prior to 2002, inspections were performed by USDA personnel, but from 2002 onwards, inspections were performed by US Customs and Border Protection. For Canada, data came from the Canadian Food Inspection Agency (CFIA) database; and for New Zealand, data came from the Wood- and Bark-Borer Interception Database (also known as BUGS), which is curated by the New Zealand Forest Research Institute (Scion) and published in Burnip et al. (2010), with more recent data from the New Zealand Ministry of Primary Industries. These data spanned the years 1914–2020 for the USA (three periods: 1914–1984 and 1985–2008, 2009–2020), 1997–2019 for Canada, and 1950–2007 for New Zealand. Databases included attributes such as interception year, consignment origin, commodity (what material the insect was found on or in), and taxonomic identification information of the intercepted specimens. Insects detected during inspections are ideally identified to the species level, but the genus or family is recorded when species identification is infeasible (e.g., when intercepted as immature stages) or the organism is deemed low-risk. Taxonomic names were updated following Schiff et al. (2012). Also, we revised the interceptions by accounting for known occurrences of siricid species in the origin country. We identified some discrepancies in the data: one native species, *Sirex varipes*, intercepted in Canada, four interceptions of *Sirex juvencus* originating from North America, three of *Tremex columba* from the Palearctic, five interceptions from the Indomalayan region, one from the Australasian, and one from Central Africa, where the identified species or genera

are not known to occur. According to Schiff et al. 2012, *S. juvencus* is a European species, and it is not established in North America, while several species are native to North America and Eastern Asia. Similarly, *T. columba* is native to North America, although other congeneric species are native to the Palearctic region. Finally, seven reports are doubtful since the identified species were not known to be established in the country of origin. These records likely result from misidentification of species, erroneous records of origin country, and/or the reuse of wood packaging materials (e.g., an insect arriving in a country and being shipped again before exiting the wood). Although the data were included in the final database, we did not use them in downstream analyses when the doubtful information was relevant for the specific analysis.

We examined commodity associations with interceptions. Because commodity reporting during inspections at USA ports varied over time, we divided the USA dataset into two periods (1950–1984 and 1985–2020). During the latter period, only the declared commodity type was reported, with no information provided on whether the insects were found on the goods or on the wood packaging material. On the contrary, the other datasets specified whether interceptions occurred on wood packaging material. In the USA and New Zealand datasets, border inspections prioritized wood packaging materials and wood-related products over other categories of imported goods. We obtained total import data at the current values in British pounds for the USA, Canada, and New Zealand from the TRADHIST database (www.cepii.fr, last accessed 10/02/2025), which includes historical monetary values of bilateral trade covering the period 1827–2014 (Fouquin and Hugot 2016). Historic data have been corrected by the Consumer Price Index (reference year 2014) from the World Bank.

For each country's database (USA, Canada, and New Zealand), we summarized interceptions by taxon, year, and consignment origin. For pre-1985 USA data, annual interceptions were aggregated across multiple countries of origin. For those aggregated entries with fewer than 10 countries and a relatively low number of interceptions (≤ 15), we split the total number of interceptions by the number of countries, assuming equal proportions. For entries with 10 or more countries and a relatively high number of

interceptions (≥ 49), we considered the origin country “unknown” unless all listed countries were on the same continent. Outdated country names were updated to reflect current demarcations. For example, imports from the USSR were treated as “Russia,” and interceptions with imports from Czechoslovakia were treated as “Czechia/Slovakia”. When the country of origin was known, we retrieved the biogeographical region of origin, e.g., European Palearctic, Asian

Palearctic, Afrotropic, Indomalaya, Australasia, Nearctic, and Neotropic, following MacLachlan et al. (2021). Finally, we included the native range of the species (Table 1) in the interception database to highlight whether the interceptions possibly originated from established populations in non-native ranges. We excluded seven interception records due to uncertain data, as the intercepted species were reported to come from African and Indomalayan countries,

Table 1 Siricidae species intercepted in the USA during port inspections between 1914–2020, in Canada during inspections between 1997–2019, and in New Zealand during inspections between 1950–2007. Data were summarized by number of interceptions, native range, and country of origin. For the native range, we used the following abbreviations: EUP=European Palearctic; ASP=Asian Palearctic; NEA=Nearctic. USA interception data are from USDA reports, APHIS database, and Worm et al. (2024); Canada data are from the Canadian Food Inspection Agency (CFIA) database; New Zealand data are from Burnip et al. (2010) and unpublished data from the New Zealand Ministry of Primary Industries. Reference for taxonomy and distributions from Schiff et al. (2012), CABI (2019), and Ge et al. (2025)

Species	Native range	Interceptions in USA	Established in the USA?	Interceptions in CAN	Established in the CAN?	Interceptions in NZL	Established in the NZL?	Notes
<i>Sirex areolatus</i>	NEA	—	—	—	—	4	N	
<i>Sirex juvencus</i>	ASP, EUP	62	N	5	N	150	N	
<i>Sirex nigricornis</i>	NEA	—	—	—	—	1	N	
<i>Sirex nitobei</i>	ASP	9	N	3	N	—	—	
<i>Sirex noctilio</i>	ASP, EUP	52	Y	2	Y	17	Y	
<i>Sirex torvus</i>	EUP	3	N	—	—	12	N	
<i>Sirex varipes</i>	NEA	—	—	1	Y	—	—	Native species
<i>Sirex</i> sp.		43		6		27		Including 6 doubtful records of <i>S. juvencus</i> in the NZL dataset
<i>Tremex abei</i>	ASP	—	—	2	N	—	—	
<i>Tremex columba</i>	NEA	—	—	3	Y	5	N	Doubtful species identity in Canada dataset
<i>Tremex fuscicornis</i>	ASP, EUP	1	N	—	—	—	—	
<i>Tremex</i> sp.		14		3		3		
<i>Urocerus albicornis</i>	NEA	—	—	—	—	1	N	
<i>Urocerus augur</i>	EUP	3	N	—	—	1	N	
<i>Urocerus fantoma</i>	EUP	1	N	—	—	—	—	
<i>Urocerus gigas</i>	ASP, EUP	62	Y	2	Y	68	N	
<i>Urocerus</i> sp.		30		5		7		
<i>Xeris spectrum</i>	ASP, EUP	19	N	2	N	41	N	
<i>Xeris tarsalis</i>	NEA	—	—	—	—	1	N	
<i>Xeris</i> sp.		11		2		5		
Siricidae		2248		45		68		

where these species are not known to exist. We performed descriptive statistical analyses in R (version 4.2.2, R Core Team 2024), using the dplyr (v1.0) package (Wickham et al., 2025) for data manipulation. The curated dataset is available in the supplementary materials as Table S1.

Finally, for all the species in our interception data, we extracted information on host trees (Liston 1995; Schiff et al. 2012; Goulet et al. 2015; EFSA Panel of Plant Health et al., 2022) and provided a table as a supplement (Table S2). For the most intercepted species, i.e., *S. juvencus*, *S. noctilio*, *U. gigas*, and *X. spectrum*, we also mapped the distribution of known host species. Host tree occurrence data were retrieved from GBIF, filtered by valid coordinates using CoordinateCleaner v3 (Zizka et al. 2019) in R, and aggregated to presence/absence at 50 km resolution.

Results

Temporal dynamics of interceptions

Our database contains 3,054 siricid interceptions: 2,562 in the USA, 81 in Canada, and 411 in New Zealand. Each record is an independent interception. The first USA record was in 1952 (no interceptions occurred from 1914–1951), with a notable spike between 1974 and 1982, peaking in 1979 with 407 interceptions (Fig. 1). The average annual number of USA siricid interceptions from 1952 to 2020 was 37.1 ± 10.7 (SE). In Canada, 81 interceptions occurred from 1997 to 2019, averaging 3.04 ± 1.03 (SE) per year. New Zealand recorded 411 interceptions from 1950 to 2007, peaking in 1994 with 23. New Zealand's annual average was 7.03 ± 0.77 (SE) interceptions, with a significant increasing trend

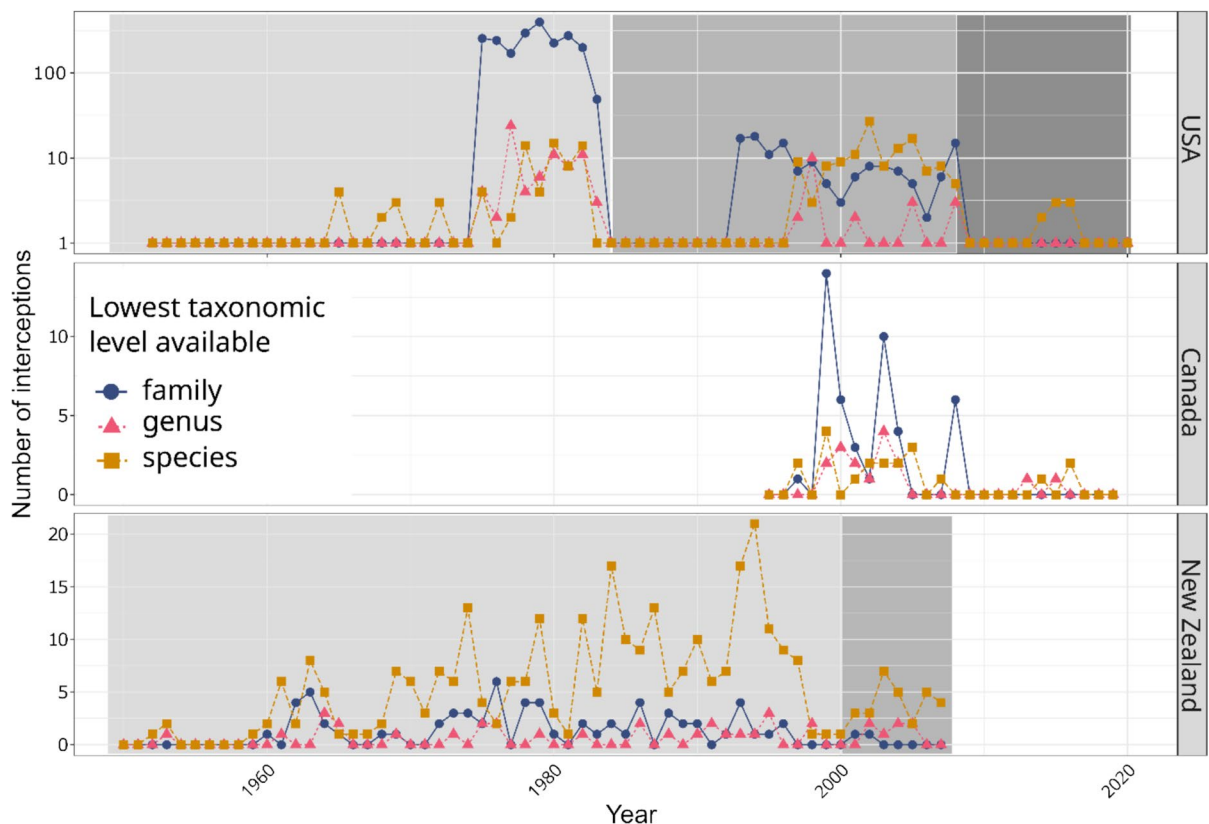


Fig. 1 Annual siricid interceptions in the USA, Canada, and New Zealand, categorized by taxonomic level of record (family: dark blue dots; genus: pink triangles; species: yellow squares). Note the logarithmic scale for USA data, start-

ing from the first interception in 1952 for comparison. For the USA and New Zealand, we highlighted the data contributions from different datasets with different grey shadows

from 1950 to 2000 (Mann–Kendall test, $z=4.24$, $p\text{-value}<0.001$).

Pathways of introduction: analysis of high-risk commodities

Packaging materials (e.g., dunnage, crates, pallets) were the primary commodities associated with siricid interceptions, accounting for 84.2% in New Zealand, 90.1% in Canada, and 97.6% in the USA (1914–1984 dataset; Fig. 2). In the USA 1984–2008 and 2009–2020 datasets, commodity recording practices changed from packaging to commodity class. Although building materials such as tiles and quarry products (42.9%), packaging materials (13.2%), metals (12.5%), and machinery (9.9%) dominated in this dataset. Many of these interceptions likely involved wood packaging materials used during transport. Wood itself (i.e., timber) and wooden objects accounted for 4.8% in New Zealand, less than 1% in

the USA for the period 1952–1984, and 7.3% in the USA for the period 1985–2020.

Biogeographic regions of origin

The USA dataset included interceptions from 29 different countries of origin; however, specific country-level data were often unavailable due to aggregated or missing information in the older data (2122 interceptions; 83%). Thus, for most of the interceptions, the biogeographical region of origin remains unknown. Most interceptions for which we had reliable records originated from the European Palearctic (16% of all interceptions), though the Asian Palearctic (2.5%) contributed more in recent decades. The proportion of imports from Asia increased dramatically from the 1950s to the 1980s (Fig. 3). Among Canada's 81 siricid interceptions, 73 (90%) had identified source countries, representing 19 different countries of origin. Interceptions predominantly came from the Asian Palearctic (61.7% of all interceptions) and European Palearctic (26%), yet imports from Asia and the European Palearctic were similar (Fig. 3). New Zealand records included interceptions from 28 countries of origin, with origins known for 322 records (78%). European Palearctic imports dominated (75% of all interceptions). Imports from the Asian Palearctic (6.3% in total) increased from the 1950s to the 1980s, mirroring USA trends and interceptions since the 1960s (Fig. 3). The European Palearctic is the most frequently represented, with presence among interceptions made across all the decades. Similarly, the Asian Palearctic and Nearctic showed a good representativeness. On the contrary, Southern hemisphere regions originated interceptions only later in the time series, with species native to the European Palearctic (i.e., *Sirex noctilio* from South Africa and *Urocus gigas* from Chile).

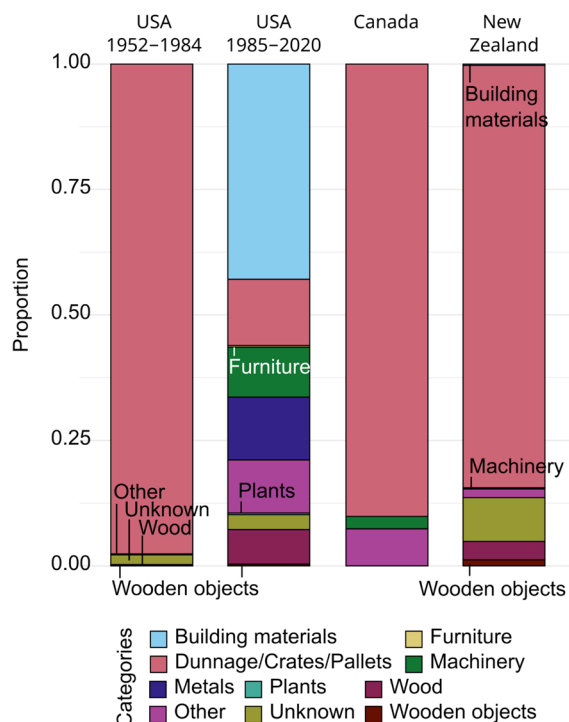
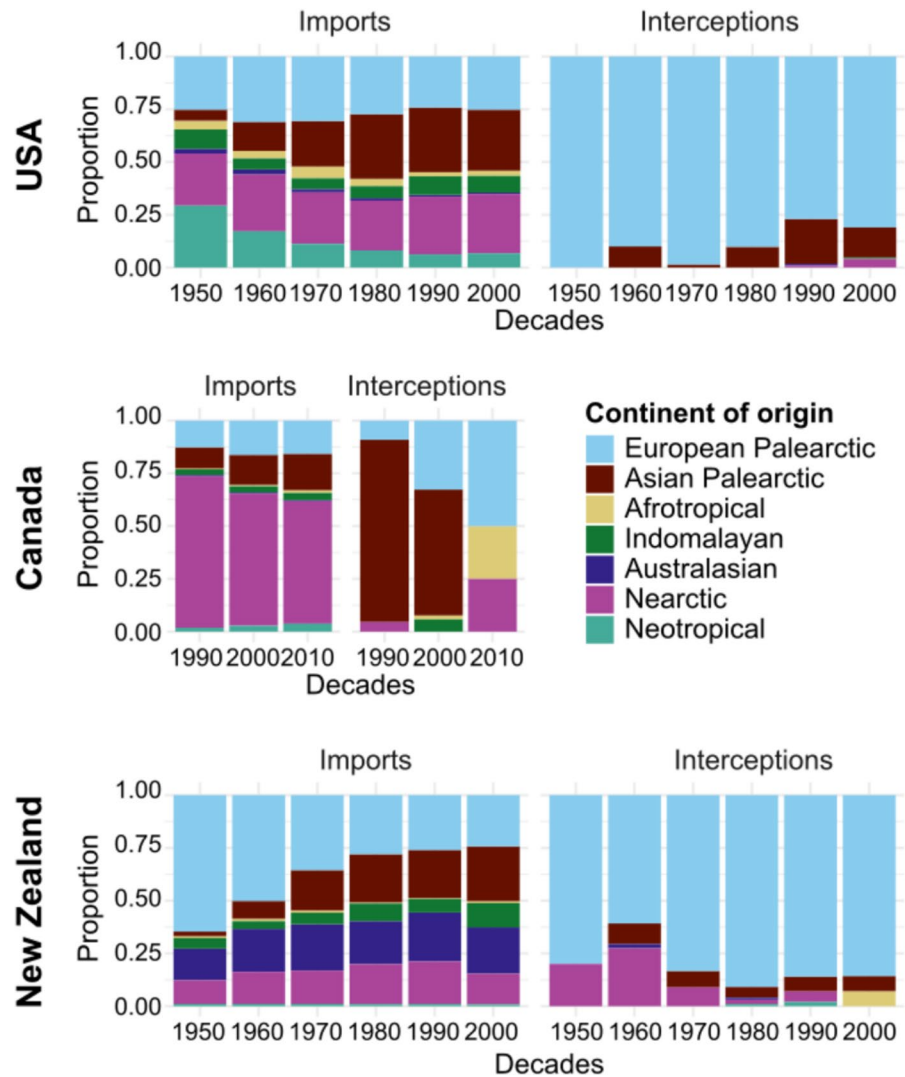


Fig. 2 Proportions of siricid interceptions by commodity type. The USA dataset is divided into 1952–1984 and 1984–2020 due to reporting differences. Because of a change in reporting practices, USA data from 1984 showed the declared commodity, without specifying whether interceptions occurred on wood packaging materials

The most frequently intercepted species of Siricidae

Only 17.8% of interceptions were identified to species level overall: 8% in the USA, 20% in Canada, and 75% in New Zealand. In the USA, eight non-native siricid species were intercepted, led by *Sirex juvencus* (64; 30%), *Urocus gigas* (62; 29%), *Sirex noctilio* (51; 23%), and *Xeris spectrum* (19; 9%). Canada had fewer interceptions than the USA and New Zealand, accounting for eight non-native species, with the most

Fig. 3 Proportions of total imports (inflation-corrected British pounds) and siricid interceptions by biogeographical region, aggregated by decade (year indicates the first year of each decade). Interception records in the USA from 2008 to 2020 lacked information on origin and were therefore removed



frequent being *S. juvencus* (5; 31%) and *Sirex nitobei* (3; 19%). New Zealand intercepted twelve non-native species, led by *S. juvencus* (150; 49%), *U. gigas* (68; 22%), *X. spectrum* (41; 13%), and *Sirex torvus* (12; 4%). Overall, 2.2% of validated interceptions with species-level information (504 total) originated outside the native range of the recorded species. For the four most abundant species, we mapped origins, noting native vs. non-native sources (Fig. 4). For *S. juvencus*, all interceptions originating from non-native areas (e.g., the Australasian and Indomalayan regions) were considered invalid because established non-native populations are unknown in these countries. For *S. noctilio*, 12.3% were from non-native regions (e.g., Nearctic, Neotropical, Afrotropical) where

the species is recorded as invasive. For *U. gigas*, 3.2% were from non-native areas (e.g., Nearctic, Neotropical). Interceptions from the Asian Palearctic (ca. 1%) are considered from native populations, although the status of *U. gigas* in China is complex (see the discussion section for further details). Finally, *X. spectrum* was intercepted only in goods from the native range (Palearctic).

Host tree species

Sirex sp., *Urocerus* sp., and *Xeris* sp. genera include many intercepted species in our dataset and are strongly associated with Pinaceae (mostly *Pinus* spp., *Picea* spp., and *Abies* spp.) and Cupressaceae.

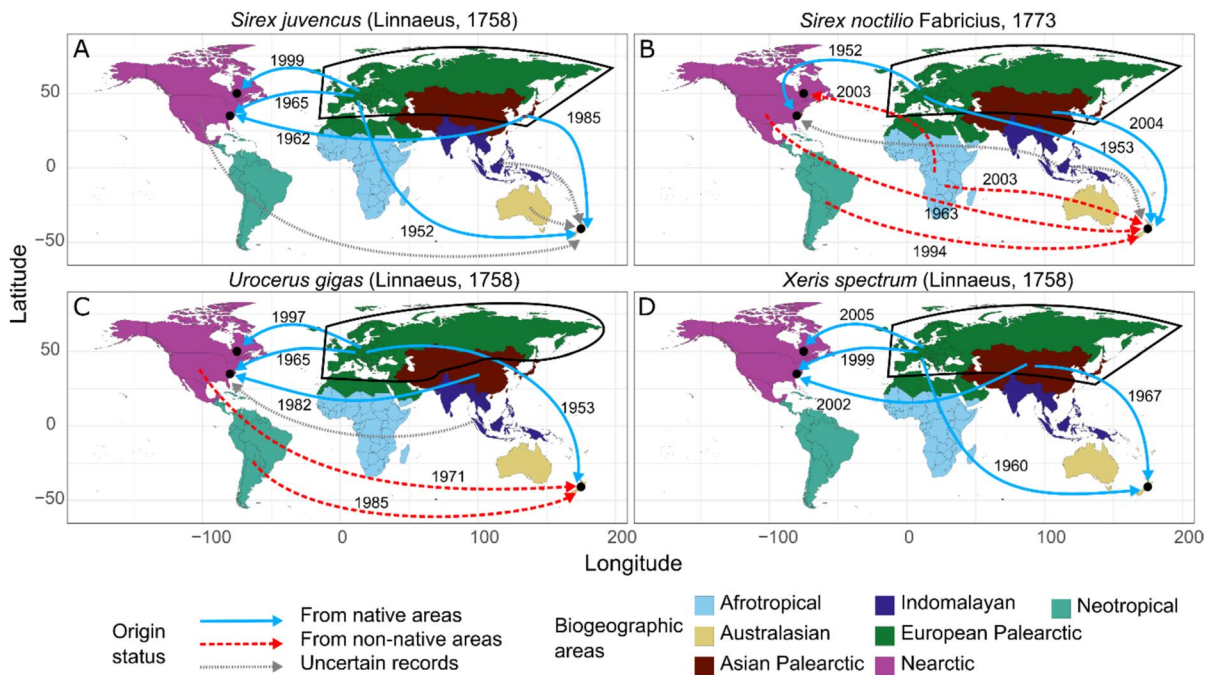


Fig. 4 Interceptions from native (blue solid arrows) and non-native (red dashed arrows) areas for *S. juvenus* (A), *S. noctilio* (B), *U. gigas* (C), and *X. spectrum* (D). Grey arrows depict

uncertain records. Native ranges are delimited by black-border polygons. Year labels refer to the first documented interception

Instead, *Tremex* spp. are associated with broad-leaves and are generally polyphagous on a wide range of host trees (Table S2). For the most intercepted species, we compiled data from the literature and mapped the distribution of the host tree species (Fig. 5). *S. juvenus* is a generalist species for *Picea* spp. (Schiff et al. 2012); *S. noctilio* feeds on many pine species (*Pinus caribaea*, *P. contorta*, *P. echinata*, *P. elliotii*, *P. kesiya*, *P. nigra*, *P. palustris*, *P. patula*, *P. pinaster*, *P. pinea*, *P. radiata*, *P. resinosa*, *P. strobus*, *P. sylvestris*, *P. taeda*) and *Pseudotsuga menziesii* (Schiff et al. 2012); *U. gigas* feeds on *Picea abies*, *P. sitchensis*, *Pinus radiata*, *P. sylvestris*, and *Pseudotsuga menziesii* (Schiff et al. 2012); *X. spectrum* feeds on *Abies alba*, *A. borisii-regis*, *A. cilicica*, *equitrojana*, *Larix decidua*, *Picea abies*, *P. orientalis*, *P. sitchensis*, *Pinus pinaster*, *P. sylvestris* (Goulet et al. 2015). Host tree occurrence data are retrieved from GBIF (last access on 25/03/2026) and aggregated in presence/absence at 50 km resolution. These host tree species mainly occur in North America; however, New Zealand and parts

of Australia, southern Africa and South America host large areas of plantations of susceptible northern hemisphere conifers (Fig. 5).

Discussion

International trade as a major driver of siricid movements across the globe

We analyzed historical siricid interceptions in the USA, Canada, and New Zealand, revealing decades of human-mediated dispersal. Interception data indicate international trade is a major driver of insect movement beyond native ranges (McCullough et al. 2006; Turner et al. 2021). Historically, a frequent association of interceptions with imports originating from Europe and Eastern Asia suggests that high volumes of specific commodities and the use of associated wood packaging materials (WPM) shaped invasion patterns (Nardi et al. 2025). However, only a small proportion of interceptions occurred on timber

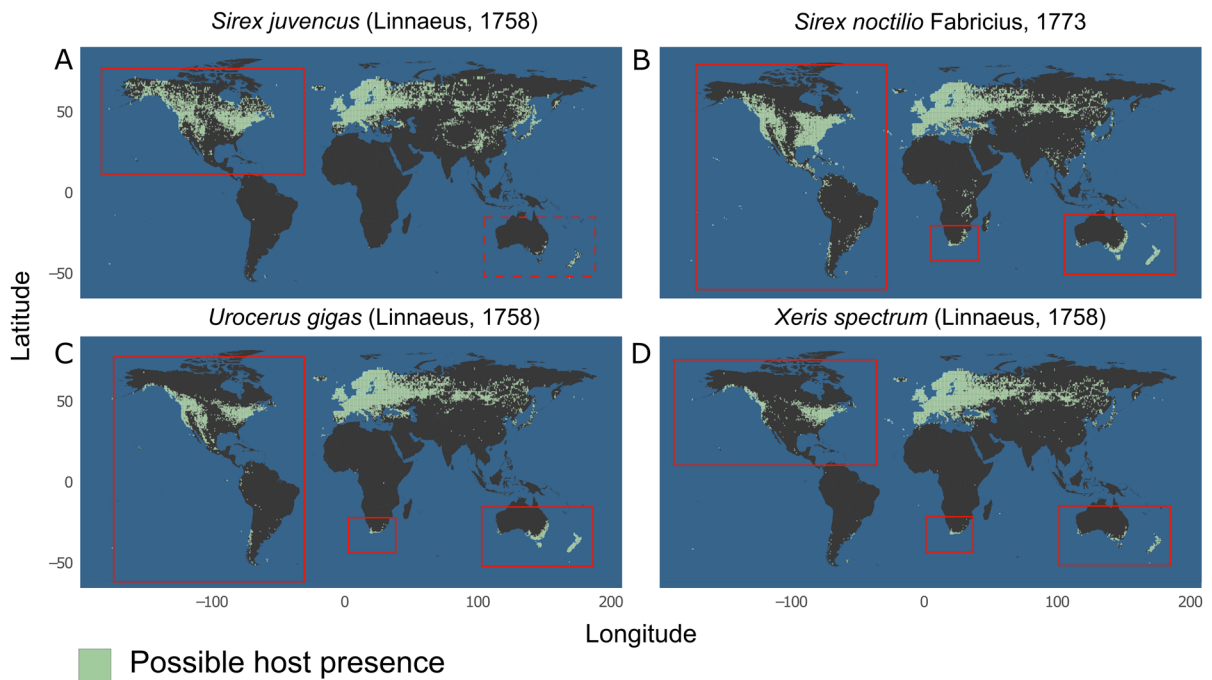


Fig. 5 Distribution of host tree species (green) for the four most intercepted species of Siricidae, *S. juvencus* (A), *S. noctilio* (B), *U. gigas* (C), *X. spectrum* (D). Host tree occurrence from GBIF are aggregated in presence/absence at 50 km reso-

lution. In red, we highlighted the siricid non-native areas with the presence of the host. The occurrence of *Picea* spp. in the southern hemisphere is rare (dashed red rectangle).

or logs, whereas these historical interception patterns, particularly those involving WPM before the widespread adoption of ISPM 15 standards, underscore the significant role of WPM as a pathway for siricid movement. While there is evidence that the implementation of ISPM 15 has significantly reduced interceptions, establishment, and damage (Haack et al. 2022, 2014; Leung et al. 2014), inspection data remain important. These inspections, although they only screen a small fraction of imports, provide invaluable data for risk analysis and serve to incentivize compliance with phytosanitary regulations by exporters and importers (Epanchin-Niell 2017; Springborn et al. 2016).

Our findings confirm wood packaging materials (e.g., dunnage, crates, pallets) as a major pathway for siricid introductions (Fig. 2), consistent with research on wood-boring insect movement (Brockerhoff et al. 2006a; Haack et al. 2014). Packaging linked to building materials like tiles and quarry products was frequently implicated, mirroring bark beetle pathways from Europe to the USA (Ward et al. 2023).

Softwoods are often used in wood packaging, especially in Europe, where *Pinus* sp. and *Picea* sp. are the most commonly used tree genera (Krishnankutty et al. 2020), as in North America. These conifers are also the principal hosts for many siricid species, serving as a primary pathway for siricid transport. To limit woodborer movement in wood packaging, the International Plant Protection Convention mandated treatments (such as fumigation or heat) via ISPM-15, which was adopted in 2002 and gradually implemented by countries between 2003 and 2006; for some countries, however, an equivalent policy was already in place as early as 1999 (Haack et al. 2014). The apparent decline in siricid interceptions in New Zealand (Burnip et al. 2010), the USA, and Canada post-2002 might suggest a positive impact of ISPM 15, aligning with evidence of reduced arrival risk (Greenwood et al. 2023; Haack et al. 2014; Leung et al. 2014), although the magnitude can vary depending on the exporting country and surveillance efforts (Haack et al. 2022). Although arrival risk is different from establishment risk and many species have never

been established after their arrival, the estimated propagule pressure using border interception data is still a good proxy for predicting establishment rates (Brockerhoff et al. 2014; Turner et al. 2020). However, the continued detection of live siricids (Burnip et al. 2010; Worm et al. 2024) highlights the necessity of strict enforcement of compliance with ISPM-15 and potentially additional mitigation strategies.

Siricid interception frequencies varied considerably over time (Fig. 1). These fluctuations likely stem more from varying inspection and reporting priorities rather than from changes in siricid arrivals via imported cargo but could also be impacted by siricid population dynamics in source localities and/or changes in trade patterns (Ward et al. 2023). Inspection priorities typically reflect biosecurity risk perceptions, which may shift with changing trade intensities and new risk analyses. Interception time series showed periods without recorded siricids, likely reflecting shifting inspection priorities rather than a true absence of arrivals (Burnip et al. 2010). Unfortunately, the high inconsistency among periods strongly limits the analysis of these historical time series. The lack of information on sampling effort (e.g., the number of inspections with no interceptions) is a common issue in interception data (Turner et al. 2024). Despite these biases, New Zealand data show temporal consistency of interceptions. Comparing the biogeographical origin composition between interception records and trade data, we showed how well-connected native regions acted as a source of propagule pressure across the time series. Europe and North America accounted for the most interceptions, according to their relevance in trade data. Interceptions from the Asian Palearctic increased sharply during the 1960s, possibly reflecting a higher proportion of imports from the region. These patterns suggest a dominant role of trade as a facilitator of siricid movements across the globe. The interceptions from non-native regions (mostly located in the southern hemisphere) appeared later in the time series, with all the identified species being native to the Palearctic region. This finding suggests an increasing role of secondary introductions (i.e., introductions from previously invaded bridgehead ranges) as the presence of invasive species into non-native areas expands. Although secondary introductions only partially contributed to species flows at the global scale in

our database, global studies highlighted that this process could play an important role in biological homogenization (Bertelsmeier and Keller 2018; Bertelsmeier and Ollier 2021; Worm et al. 2024). In particular, even a few countries acting as trade hubs, i.e., importing high amounts of commodities from other biogeographic regions and exporting both at the intercontinental and sub-continental scale (Capinha et al. 2023; Nardi et al. 2025), can potentially shape the overall trade network and accelerate insect spread via the bridgehead effect (Bertelsmeier et al. 2018; Lesieur et al. 2019). Our historical interception data suggest that additional propagule pressure has originated from non-native areas since the 1960s for multiple siricid species (Fig. 4), posing ongoing secondary invasion risks despite low total numbers of interceptions.

A taxonomically complex family

While *S. noctilio* garners significant attention due to its documented damage in non-native ranges, other frequently intercepted siricids, such as *Sirex juvenicus* (215 total interceptions among Canada, the USA, and New Zealand) and *Sirex nitobei* (3 interceptions in Canada and 9 in the USA), remain understudied despite being frequently intercepted. *Sirex juvenicus* has been frequently intercepted since the 1950s; however, there is no evidence of its establishment outside its native range. The taxonomy of this genus has recently been revised, indicating that previous records of *S. juvenicus* actually correspond to two species (Ge et al. 2025), namely *S. juvenicus* and the recently described *S. dux*. In North America, multiple native species resemble *S. juvenicus*, namely *Sirex nitidus*, *Sirex cyaneus*, *Sirex abietinus*, and *Sirex californicus*. According to Schiff et al. (2012), *S. juvenicus* is not present in North America. Similarly, several subspecies of *Urocerus gigas* have been reported from the Palearctic regions. In China, both *U. gigas taiganus* and *U. gigas orientalis* have been recorded (Taeger et al., 2026; Wei et al. 2006), and *U. gigas tibetanus* has been stated as introduced in the 1980s in the country (Xu et al. 2012). The taxonomic confusion around these genera, the presence of many cryptic species, and the absence of reliable morphological features may significantly affect previous identifications in the interceptions of other species from North America and Asia, contributing to the high proportion

of identification uncertainty in the border interception records.

Investigating the reasons for an invasion's success

Historical interceptions illuminate biological invasion complexity. Usually, arrivals are key factors for assessing the risk of biological invasions; however, interceptions may not fully reflect propagule pressure (Brockerhoff et al. 2014; Turner et al. 2024), and establishment requires suitable conditions, including host and environmental suitability (Daly et al. 2023; Enders et al. 2020). Competition or climatic mismatches could also play roles, warranting research on species tolerances under climate change (Johnson and Haynes 2023). Using historical interceptions, we highlighted these mismatches between siricid interception frequency and their establishment.

Host availability is an important limiting factor for the establishment of siricid worldwide, and it might have contributed to their spread. While *S. noctilio* and *U. gigas* are mainly associated with *Pinus* hosts, *S. juvencus* prefers *Picea* (Schiff et al. 2012). *Picea* spp. are less common in the southern hemisphere, which may suggest lower host availability for *S. juvencus* (Gao and Shi 2021). On the contrary, *Pinus* spp. are widespread in North America and have been widely planted in the Southern hemisphere (Burgess and Wingfield 2001), allowing a large availability of hosts for *S. noctilio* and *U. gigas* (Fig. 5). Among Asian species, *Sirex nitobei* merits detailed investigation due to its association with widespread *Pinus* species. The apparently lower propagule pressure of Asian woodwasp species may be due to less common use of suitable host material in commercial trade with Asian countries, which might have limited their dispersion. Nevertheless, their repeated detection, particularly on dunnage, signals a potential invasion risk. Despite the high diversity within the *Sirex* genus, only *S. noctilio* has established populations in the USA and New Zealand (and several other countries), suggesting other factors have prevented the establishment of other *Sirex* species in these and other regions so far, such as biological, environmental, or dispersal barriers. Global taxonomic revisions and targeted risk assessments are necessary, and other *Sirex* species urgently need to be evaluated for their establishment potential, host specificity, climatic tolerances, and potential for damage.

The relationships between woodwasps and the associated symbiont basidiomycete fungi *Amylostereum* spp. add even more complexity (Thomsen et al., 2011). The spillover of specific fungal strains carried by the European species *S. noctilio* to American *Urocerus* species shows that horizontal transfers are possible (Hajek et al. 2018). So far, these ecological symbiotic relations could also serve as a limitation for the further spread of siricids. *Xeris spectrum* is another species that has been intercepted often in New Zealand, but it has not become established there, despite the presence of suitable host trees. This species does not carry symbiotic fungi by itself, but its reproductive strategy involves oviposition on trees already infested with *Amylostereum* fungus (Fukuda and Hiji 1997; Spradbery 1977). This strategy leads to a certain ecological complexity and ecological constraints, suggesting a reason why this species has not become established, despite having been intercepted often.

A roadmap towards a science-based interception dataset for siricids

The critical role of accurate taxonomic identification

Precise taxonomic identification is critical for effective biosecurity. The lack of species identification among 75.3% of Siricidae interceptions in Canada, 25.3% in New Zealand, and 91.6% in the USA reported here highlights a significant challenge. Although it can be partially attributed to the fact that larvae are the most frequently intercepted siricid life stage and require much more specialized training and time to identify than adult siricids, the high variability among these three countries suggests that identification performance can also be enhanced. Misidentification of adults within similar species, such as those in the *Sirex* genus, also risks inaccurate assessments and potentially misdirected efforts. Identifying adult female siricid species requires detailed examination of minute features such as antennal segments and genital pitting (Schiff et al. 2012; Sun et al. 2016). Taxonomic revisions (e.g., *S. cyaneus* and *S. juvencus* in Schiff et al. 2012; Asian species of *Sirex* spp. in Ge et al. 2025; and *Xeris* genus revision in Goulet et al. 2015) emphasize the need for updated training and

resources. Although identification based on morphological traits is important, additional tools (e.g., barcoding) have been developed in the last few decades (Goulet 2012). Molecular diagnostics can enhance rapid, accurate biosecurity identification, even for larvae, and potentially greatly decrease the number of unidentified interceptions (Poland and Rassati 2019). Furthermore, the sequence can be deposited and used for a posteriori identification even when the specimen is lost, despite several limitations (Goulet et al. 2015). For this reason, a checked, accurate, and reliable molecular database can serve as a reference for identification. Improved identification may require border biosecurity agencies to identify specimens using molecular tools, to preserve adult specimens when possible, and to deposit barcoding sequences.

Dealing with historical data

Here, we used historical data to explore siricid interception patterns in three countries. Despite the importance of such data in studying past biological invasions, the data often need to be checked, and their limitations (e.g., misidentifications, missing data) should be considered. Updating the species taxonomy might not be sufficient, and species identities should be revised based on their origins, especially for historic data involving border interceptions. Recent revisions in North America and Asia (Schiff et al. 2012; Ge et al. 2025) allowed us to reassign species identity based on their country of origin and separate possible different species belonging to the same group. For example, there is no evidence that *S. juvencus* has established populations in North America (Schiff et al. 2012), despite being frequently intercepted at the border. However, in North America, there are many similar species, such as *S. nitidus*, *S. varypes*, *S. cyaneus*, and *S. abietinus*, which may have been erroneously assigned to *S. juvencus*. In Asia, this species is present and widespread in temperate climatic regimes (Ge et al. 2025); however, Schiff et al. (2012) found that some Asian specimens labelled as *S. juvencus* were actually other species. The difficulty in distinguishing species within the family Siricidae and the confusing taxonomy in the past could have led to misidentifications in the reports of border interceptions worldwide. We thus strongly recommend that

historical data be cautiously curated and interpreted before downstream analyses.

Furthermore, interception data spanning several decades usually lack information on sampling effort, which can be extremely variable over time (Saccaggi et al. 2016). This limitation impedes the exploitation of all the valuable information in these datasets. The omission of zeros (i.e., absences) is a common problem in ecology, especially when datasets are based on opportunistic data or when the focus is on detection, as in border interceptions. Also, the number of inspectors can be used as another proxy of sampling effort for interceptions for comparison across time; usually, this is not available as well. Finally, the border control regimes can vary across different countries (Bacon et al. 2012), and sometimes inspectors can assign different priorities depending on pathway characteristics, such as the type of goods and provenance. This biased inspection strategy can also reflect on interceptions, thus leading to a biased conclusion. Future interception data could integrate this information along with interceptions to account for these factors.

Ecological knowledge in support of risk assessment

The ecological knowledge of this group of insects is often scarce or based on a few common species, such as *S. noctilio* (Slippers et al. 2015). However, the recent introductions of other alien species of siricids across the globe (e.g., Kuramitsu et al. 2019; López et al. 2012; Lantschner and Villacide 2025) suggest that global trade is still acting as a dispersion driver leading to the establishment of non-native species. Also, the increasing number of non-native species might lead to more possible interactions. For instance, interspecific transmission of symbionts that has already occurred for some species (Hajek et al. 2018) could open new insights into the invasiveness of alien siricids or new host-symbiont-pest interactions under climate change. Understanding the ecological mechanisms underlying successful establishments in non-native regions for the most intercepted siricid species and delimiting the actual possible hosts will improve future risk assessments (Lantschner and Villacide 2025).

Conclusions

Interception data reveal historically frequent arrivals of non-native siricids via international trade and, in particular, the widespread use of wood packaging materials with many different commodities. The increase in global trade heightens the risk of introducing harmful forest pests, such as siricids. Although the worldwide implementation of ISPM 15 has likely reduced the infestation rate of wood packaging material, issues with apparent non-compliance need attention. Understanding the sources and movement patterns of siricids in international trade networks can help inform policies and minimize the establishment of new species. Historical interception datasets, after careful curation, can inform biosecurity strategies to mitigate these threats; however, new standards for data quality and ancillary information are needed to ensure the full exploitation of these valuable data.

Data availability statement

All data that support the findings of this study are included within this paper and its Supplementary Information files (Table S1 and Table S2).

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Declarations

Competing interest The authors have no relevant financial or non-financial interests to disclose.

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