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Evolving management strategies for a recently discovered exotic forest pest: the pine shoot beetle, *Tomicus piniperda* (Coleoptera)*

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Abstract

Established populations of the Eurasian pine shoot beetle (*Tomicus piniperda* (L.); Coleoptera: Scolytidae) were first discovered in North America in Ohio in 1992. As of 31 December 2000, *T. piniperda* was found in 303 counties in 12 US states (Illinois, Indiana, Maine, Maryland, Michigan, New Hampshire, New York, Ohio, Pennsylvania, Vermont, West Virginia, and Wisconsin) and in 43 counties in 2 Canadian provinces (Ontario and Quebec). A federal quarantine imposed in November 1992 regulates movement of pine (*Pinus*) trees, logs, and certain pine products from infested to uninfested areas within US. The forest products, Christmas tree, and nursery industries are affected by the quarantine. This paper summarizes information on the discovery and spread of *T. piniperda* in North America, survey efforts, recent interception history, development and changes in the federal quarantine, development of a national compliance management program, and extension and research efforts.

Introduction

Animal and plant species from one world region are often inadvertently introduced to other regions as a result of world trade and travel (US Congress 1993). In US, more than 2000 species of exotic insects are now established (US Congress 1993) and over 400 of these species feed on trees and shrubs (Mattson et al. 1994; Liebhold et al. 1995; Niemela and Mattson 1996). Many of these exotic forest insects were first reported during the past decade, including several species of bark beetles (Coleoptera: Scolytidae) (Haack and Kucera 1993; Hoebeke 1994, 2001). It is not surprising that new exotic scolytids are regularly discovered in the US given that scolytids accounted for 62% of the nearly 7000 insect interceptions made by US Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) inspectors on solid wood packing materials at US ports of entry during 1985–1998 (Haack and Cavey 2000).

Upon discovery of a new exotic organism in the US, APHIS organizes a 'New Pest Advisory Group' that consists of regulatory officials and specialists. This group meets on various occasions to discuss the known biology of the organism, its potential damage and range, mitigation strategies, and the possible need for a domestic (internal) quarantine. Based on these discussions, the New Pest Advisory Group makes a recommendation to APHIS to either take action on the newly detected exotic pest or not. When a domestic quarantine is enacted, it is often first based on scientific literature from those countries where the organism already occurs and then later modified as new research findings are produced locally. The typical goal of a domestic quarantine is to minimize human-assisted movement of potentially infested host material by regulating the various pathways by which the host

material is moved. This paper describes the quarantine history of one exotic bark beetle that was recently discovered in North America – the pine shoot beetle, *Tomicus piniperda* (L.) (Haack 1997; Haack et al. 1997).

Range and biology of *T. piniperda*

Tomicus piniperda is primarily a pest of pine, *Pinus* spp., throughout its native range of Europe, Asia, and north Africa (Bakke 1968; Långström 1983; Ye 1991). *Tomicus piniperda* has been reported from Portugal east to Japan and from the Arctic Circle in Scandinavia and Russia south to northern Africa and southern China (Wood and Bright 1992). The establishment of *T. piniperda* in North America is the first reported range expansion of this species to a new continent.

The general biology of *T. piniperda* is well documented (Bakke 1968; Salonen 1973; Långström 1983; Schroeder 1988; Ye 1991; Haack and Lawrence 1995a; Haack et al. 1998, 2001; Kauffman et al. 1998; Petrice et al. 2002). *Tomicus piniperda* completes one generation per year throughout its range. In late winter or early spring, when daily high temperatures begin to exceed 10–13 °C, *T. piniperda* adults initiate flight from their overwintering sites and seek breeding material such as recently cut pine trees, logs, branches, and stumps. *Tomicus piniperda* will also breed in live pine trees that have been severely stressed. Adult beetles appear to locate these materials by means of host volatiles such as alpha-pinene. After landing, each adult female chews her way into the inner bark where she is soon joined by a single male. After mating, each female constructs a longitudinal 'egg gallery' that runs parallel with the wood grain. Eggs are laid individually in niches cut along the walls of the gallery. After constructing an egg gallery, some parent adults reemerge and they either immediately seek other host material to construct new egg galleries or they fly to live pine trees and shoot-feed before constructing new galleries. Progeny complete their development and emerge as adults from the brood material starting in early summer. Instead of initiating a second generation, the new adults fly to the crowns of pine trees and feed inside the shoots throughout summer and autumn. During this period of maturation feeding, the progeny adults become sexually mature. Then, in areas where winters are severe, adults exit the shoots in apparent response to the first few hard freezes in autumn, and move to overwintering sites inside the outer bark at the base of live pine trees. In areas with mild winter temperatures, such as parts of southern Europe and southern China, *T. piniperda* adults typically overwinter inside the shoots.

Initial discovery of *T. piniperda* in North America

In North America, established populations of *T. piniperda* were first discovered near Cleveland, Ohio, in July 1992 (Haack and Kucera 1993; Haack 1997; Haack et al. 1997). The initial discovery occurred when a manager of a Christmas tree plantation collected some unknown beetle adults from inside shoots of pine Christmas trees on 1 July 1992. The beetles were delivered to a local entomologist (Dr David G. Nielsen, Ohio State University) who in turn sent them to Dr Stephen L. Wood (Brigham Young University, Utah) for positive identification. Dr Wood identified the beetles as *T. piniperda* in a letter dated 16 July 1992, and Dr Nielsen subsequently notified APHIS on 22 July about the discovery.

On 23 July 1992, APHIS established a 'New Pest Advisory Group' to evaluate the potential pest status of this insect and options for quarantine and control. On 24 July, APHIS electronically notified regulatory and extension agencies throughout the US about the presence of *T. piniperda* in Ohio. In the days that followed, *T. piniperda* was found at several nearby Christmas tree plantations and nurseries in Ohio. Several training sessions were soon held in Ohio to educate APHIS inspectors and plant health specialists from nearby states on how to identify *T. piniperda* and its associated damage. State and federal regulatory personnel began to inspect pine Christmas trees and nurseries in surrounding states, and within one month of the initial USDA announcement, five new states reported finding *T. piniperda*: Indiana on 4 August, Pennsylvania on 13 August, Michigan on 14 August, New York on 20 August, and Illinois on 21 August 1992.

It is reasonable that *T. piniperda* had been in the US for several years before its discovery given that it was found in six states during a four-week period in 1992, an area more than 800 km wide east to west and 300 km long north to south. Once *T. piniperda* was discovered in Michigan in 1992, a local entomologist found a previously unidentified *T. piniperda* specimen in his personal collection that he had removed from a shoot of an eastern white pine, *Pinus strobus* L., tree in Ingham County, Michigan, in 1991. In one Scotch pine,

Pinus sylvestris L., plantation with high *T. piniperda* populations in New York, growth-ring analysis indicated that severe shoot-feeding damage, presumably caused by *T. piniperda*, had occurred since the late 1980s (Czokajlo et al. 1997).

Surveys and range expansion of *T. piniperda*

APHIS has never mandated that all US states use a standard survey design and trapping method for *T. piniperda* and therefore survey efforts have varied widely from state to state (Table 1). For APHIS to consider a county to be infested, only a single adult had to be collected in a trap, trap log, or shoot anywhere within the county. Some have argued that a threshold of one beetle is too low. On the other hand, others have argued that based on mark-release-recapture studies of *T. piniperda* (Barak et al. 2000; Poland et al. 2000), collecting a single adult would typically signify the presence of a much larger local population given that only a small percentage of insects are ever recaptured. There has also been variation from state to state as to where surveys are conducted. Most surveys take place in Christmas tree plantations, but some surveys occur in tree nurseries, forested areas with recent logging activity, and near sawmills. Populations of *T. piniperda* can easily maintain themselves in pine Christmas tree plantations because recently cut stumps and trees are usually available every spring to support reproduction and live pine trees are always present to support shoot feeding and overwintering. It has been our experience that *T. piniperda* will most commonly be found in Christmas tree plantations that consist largely of Scotch pine and are poorly managed (e.g. few insecticide applications, and leaving high stumps and cull trees as breeding material).

By the end of 1992, *T. piniperda* was found in 43 counties in the six states of Illinois, Indiana, Michigan, Ohio, Pennsylvania, and New York (Table 1, Figure 1). Surveys during 1993 and 1994 found several new infested counties but no new infested states. *Tomicus piniperda* was first found in Maryland and West Virginia in 1995, Wisconsin in 1997, New Hampshire and Vermont in 1999, and Maine in 2000. On average, *T. piniperda* was found in more than 30 new counties per year from 1992 to 2000 (Table 1). As of December 2000, *T. piniperda* was known to occur in 303 counties in the US. During 1993–2000, US states within and near the quarantine zone used a combination of trap logs and alpha-pinene baited funnel traps to capture parent adults during their initial spring flight, and

Table 1. Historical information on the discovery and spread of *T. piniperda* in North America, including the year when *T. piniperda* was first detected, the cumulative number of quarantined counties by year during 1992–2000, and information on the trapping program within each US state or Canadian province during 1997–2000.

State or province	Year of initial discovery	Cumulative number of positive counties by year									Trapping program (1997–2000)	
		1992	1993	1994	1995	1996	1997	1998	1999	2000	No. traps per county in buffer	Trapping buffer width (no. counties)
Illinois	1992	2	7	10	15	22	24	24	25	27	3–13	1
Indiana	1992	18	26	31	31	32	37	40	45	51	10–12	1–3
Michigan	1992	4	30	37	37	52	65	70	74	74	4–18	1–5
Ohio	1992	14	16	18	31	43	49	54	54	71	2–5	1-4
New York	1992	2	10	12	14	16	19	22	29	32	10	1–2
Pennsylvania	1992	3	3	10	18	19	23	25	29	30	5–10	2–5
Maryland	1995	0	0	0	1	1	3	3	3	4	9–15	1–8
West Virginia	1995	0	0	0	1	2	3	4	6	6	10	1–8
Wisconsin	1997	0	0	0	0	0	1	1	3	3	2–4	1–8
New Hampshire	1999	0	0	0	0	0	0	0	1	1	10	1
Vermont	1999	0	0	0	0	0	0	0	2	3	10	1
Maine	2000	0	0	0	0	0	0	0	0	1	10	1
US total		43	92	118	148	187	224	243	271	303		
Ontario	1993	0	7	10	14	17	18	23	25	30	[a]	[a]
Quebec	1998	0	0	0	0	0	0	1	8	13	[a]	[a]
Canada total		0	7	10	14	17	18	24	33	43		

[a] *Tomicus piniperda* surveys in Canada are targeted at high risk sites such as sawmills, Christmas tree farms, and pine plantations. Surveys have employed trap logs, baited funnel traps, and visual inspections. Survey efforts have increased each year. In 2000, 250 sites were trapped in Ontario and 495 sites were trapped in Quebec with one to two funnel traps placed at each site (*Source*: Canadian Food Inspection Agency).

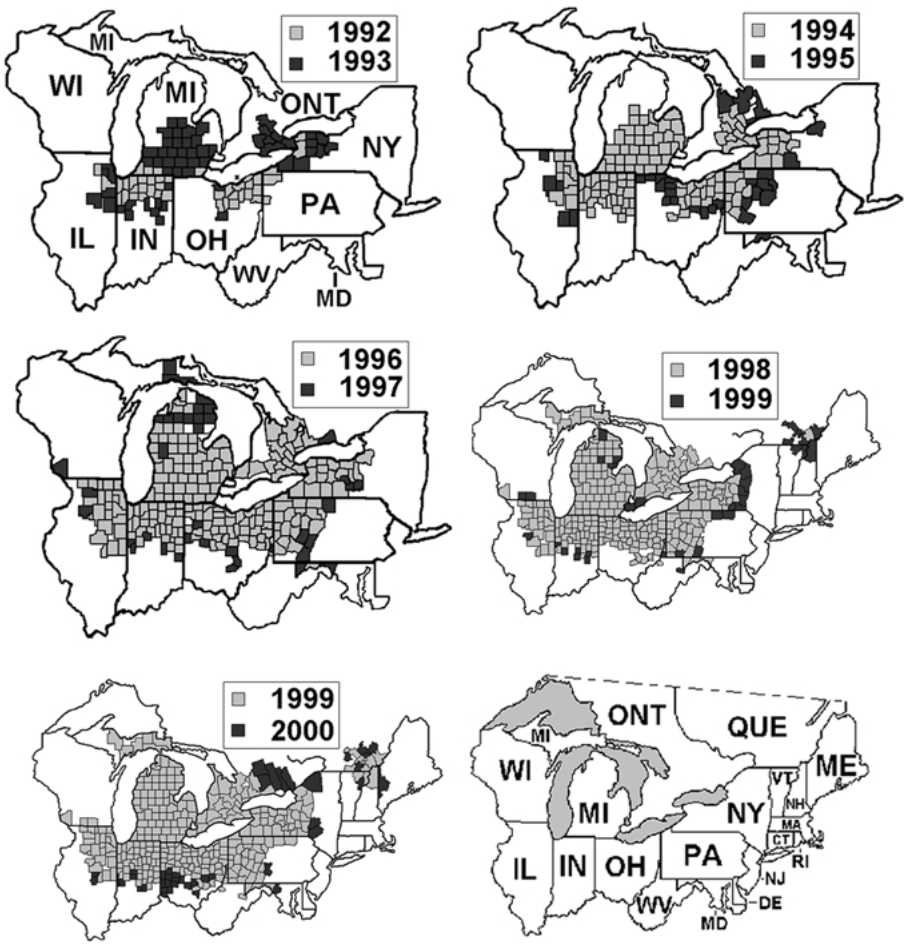

Figure 1. Known distribution of *T. piniperda*-infested counties in North America at the end of each year from 1992 through 2000; *Source*: USDA APHIS and Canadian Food Inspection Agency. For each individual map, the lightly shaded counties represent the known range of *T. piniperda* at the end of the first year stated (1992, 1994, 1996, 1998, and 1999), while the darker-shaded counties represent the new counties that were found to be infested by the end of that particular year (1993, 1995, 1997, 1999, and 2000). Abbreviations are: CT = Connecticut, DE = Delaware, IL = Illinois, IN = Indiana, MA = Massachusetts, MD = Maryland, ME = Maine, MI = Michigan, NH = New Hampshire, NJ = New Jersey, NY = New York, OH = Ohio, ONT = Ontario, PA = Pennsylvania, QUE = Quebec, RI = Rhode island, VT = Vermont, WV = West Virginia, and WI = Wisconsin.

visual surveys during late summer and autumn to locate *T. piniperda*-associated shoot-feeding damage. In more recent years, all infested states have surveyed only with alpha-pinene baited traps in spring and early summer. Although the infested states now use similar traps and lures, their survey efforts still vary in the number of traps deployed per county and the width of the buffer zone that is trapped each year (Table 1).

In Canada, *T. piniperda* was first detected in Ontario in 1993 and then in Quebec in 1998 (Table 1, Figure 1). As of December 2000, *T. piniperda* was known to occur in 43 counties in Canada (Table 1). Canada initially used a combination of baited traps, trap logs, and visual inspections. In more recent years, Canada has also moved to using only alpha-pinene baited traps.

The rapid increase in the number of infested US counties between 1992 and 1993 (43–92 counties; Table 1), is likely more a reflection of increased survey effort and experience than of natural spread by the beetle. However, the number of newly infested counties found during 1995–2000 is probably more indicative of the natural rate of spread. Nevertheless, given the variability in trapping effort from state to state, the actual geographic range of *T. piniperda* in any given year and its rate of spread will never be known with certainty.

It is not known how the disjunct infestation in Quebec and the New England states occurred (Figure 1). One theory is that *T. piniperda* was inadvertently moved on infested pine logs, while others suggest natural long-range dispersal from disjunct infestations in North America or even another separate introduction from Eurasia. DNA analysis of several *T. piniperda* populations collected in the US in 1993, suggested that *T. piniperda* was introduced on at least two separate occasions (Carter et al. 1996). The first introduction likely occurred somewhere in Ohio, while a second and more recent introduction apparently occurred in Illinois.

Up until 2000, all infested US states worked with APHIS to enforce the *T. piniperda* federal quarantine at the county level. However, in 2001, West Virginia became the first state to decide that it was in the best economic interest of their forest industries to classify their entire state as infested (Table 2), and thus annual surveys will stop in West Virginia. If other states follow West Virginia's lead, it will become increasingly more difficult to track *T. piniperda*'s future range expansion at the county level, but tracking range expansion at the state level would still be possible.

Recent interception history

Tomicus piniperda is regularly intercepted at US ports of entry (Table 3, Figure 2). During the 16-year period 1985–2000, *T. piniperda* was intercepted 151 times on cargo arriving from at least 18 different countries (Table 3). The *T. piniperda* interception rate fell from about 20 interceptions per year in 1985–1986 to about 5 per year during 1995–2000 (Figure 2). When the type of wood article was specified (114 interceptions), most interceptions were made on dunnage (70% of 114 interceptions) and crating (27%; Table 3). Nearly 64% of the 151 interceptions were made on shipments arriving from France, Italy, UK, and Spain (Table 3). Interceptions were made at 24 US ports with most occurring at Toledo, Ohio (39 interceptions); Miami, Florida (21); Detroit, Michigan (12); Houston, Texas (12), and New Orleans, Louisiana (12). Overall, about 44% of the 151 *T. piniperda* interceptions were in port cities along the Great Lakes (Figure 3). Of the 42 interceptions made in Ohio, where *T. piniperda* likely first became established, 19 were on cargo from UK, 12 from France, 5 from Belgium, 2 from Russia, 1 from Lithuania, 1 from Sweden, and 2 from unknown countries. Such interception data can suggest the likely countries of origin for a newly detected exotic pest, but interception records alone are not conclusive. If sufficient genetic variation exists across the native range of a given organism, various DNA techniques could be used to identify likely origins when this organism is found in a new part of the world. In such situations, interception data could help narrow the screening process when working with organisms that occur over a wide geographic range.

Interceptions of *T. piniperda* in the US have been made during every month of the year, but mostly during June and July (Table 4). The most common countries of origin change throughout the year, possibly reflecting temperature-related differences in timing of initial spring flight and activity across *T. piniperda*'s native range (Table 4). For example, southern European countries such as Italy and Spain are the most common sources for interceptions made during December through April, while more northern European countries such as France, Germany, and UK are the most common sources during May through November (Table 4). During 1985–1998, *T. piniperda* was the seventh most commonly intercepted scolytid on wood articles at US ports (Haack and Cavey 2000).

Quarantine history

When there is no federal quarantine for a given exotic pest in the US, any uninfested state can enact its own state-level quarantine on potential host material from the infested states. During September and October 1992, seven US states (i.e. Florida, Georgia, Kansas, Louisiana, North Carolina, Oregon, and West Virginia) imposed their own state-level quarantines on various pine articles from the six infested states (Haack 1997). Requirements within these seven state quarantines ranged from allowing importation of the regulated articles after being inspected and declared free of *T. piniperda* (e.g. Florida and North Carolina) to prohibiting all regulated articles (e.g. Kansas). In November 1992, USDA APHIS imposed a federal *T. piniperda* quarantine on the movement of host material from regulated (infested) areas to unregulated (not known to be infested) areas within the US (USDA APHIS 1992).

Many people within the infested region of the US welcomed the federal quarantine because it established one standard set of rules for the entire country. When a federal quarantine exists in the US, no state quarantine can be imposed that has stricter requirements

Table 2. Date of publication and summary of federal actions taken by USDA APHIS on *T. piniperda* as published in the US Federal Register from 1992 through April 2001.

Date	Citation	Summary
19 Nov 1992	57: 54496–54499	Domestic quarantine notice. Regulated pine Christmas trees, using specified inspection protocols and tables. Allowed for fumigation of Christmas trees. Prohibited movement of pine nursery stock greater than 24 inches tall. Allowed movement of pine, fir, spruce and larch logs and lumber with bark attached after fumigation. Listed 42 counties in IL, IN, MI, NY, OH, and PA as infested
28 Jan 1993	58: 6346–6348	Interim rule. Cold treatment allowed as an option for pine Christmas trees and pine nursery stock (-20.6° C for 1 h). Allowed movement of pine nursery stock after complete inspection of each plant shipped; allowed for certification of individual trees. Added 1 county in IL
13 May 1993	58: 28333–28335	Interim rule. Removed fir, spruce and larch logs and lumber with bark attached from list of regulated articles. Added pine bark, chips, and stumps as regulated articles with fumigation option. All pine logs, lumber and stumps allowed to move freely if cut and transported during months of July through October. Pine nursery stock less than 36 inches tall with a trunk diameter of 1 inch or less at groundline was no longer regulated. Added 1 county in MI
29 Jun 1993	58: 34681–34683	Interim rule. Definition of seedling broadened to include transplants. Added 11 counties in IN and MI
30 Nov 1993	58: 63024–63027	Interim rule. Added new treatment schedule for methyl bromide fumigation of Christmas trees. Added 37 counties in IL, IN, MI, NY, and OH
5 Aug 1994	59: 39937–39941	Interim rule. Added 18 counties in IL, IN, MI, NY, and PA
20 Oct 1994	59: 52891–52894	Interim rule. Added 6 counties in IL, MI, NY, and OH
9 Jan 1995	60: 2321–2323	Interim rule. Added 2 counties in IN
3 Nov 1995	60: 55777–55781	Interim rule. Added 28 counties in IL, NY, OH, PA, MD, and WV. Added raw materials for pine wreaths and garlands and the finished products to list of regulated articles. Treatment options allowed for cold treatment or fumigation
31 Jan 1996	61: 3176–3177	Final rule. All changes made between November 1992 and January 1995 were made final
9 Dec 1997	62: 64677–64680	Interim rule. Added 78 counties in IL, IN, MD, MI, NY, OH, PA, WV, and WI
7 May 1998	63: 25153–25155	Final rule. Added 78 counties
5 Jan 1999	64: 385–387	Interim rule. Added 19 counties in IL, MI, NY, OH, PA, and WV
2 Apr 1999	64: 15916–15918	Final rule. Added 19 counties
21 Dec 1999	64: 71322–71323	Proposed rule. Proposed to remove finished pine wreaths and garlands from list of regulated articles, but kept as regulated the raw materials for pine wreaths and garlands
19 Jun 2000	65: 37841–37842	Interim rule. Added 28 counties in IL, IN, MI, NH, NY, PA, VT, WV, and WI
28 Jun 2000	65: 39853–39854	Notice of public meetings and request for comment. Three public meetings were announced to take place during July 2000 in Georgia, New York, and Oregon to discuss the future of the pine shoot beetle program, how to improve it, and how to fund it
24 Aug 2000	65: 51517–51518	Final rule. Removed finished pine wreaths and garlands from list of regulated articles
6 Mar 2001	66: 13484–13485	Notice of availability and request for comment. Requested public comment on a draft environmental assessment by USDA APHIS that dealt with importation of pine shoot beetle host materials from Canada into the US
20 Apr 2001	66: 20185–20186	Final rule. Added 28 counties
18 July 2001	66: 37401–37405	Interim rule. Added 83 counties in IL, IN, ME, MD, NY, OH, PA, VT, and WV, which included all 50 remaining counties in WV

than the federal quarantine. Since being enacted in 1992, the federal *T. piniperda* quarantine has undergone several revisions (Table 2). Scientific literature from Europe and Asia was used as the foundation for much of the original federal quarantine. However, as more was learned about *T. piniperda* in the US and the practices of the affected industries, several modifications were made to the federal quarantine. During the period 1992–2000, the federal quarantine has regulated the movement of logs and lumber, Christmas trees, nursery stock, stumps, bark, and both the raw materials and finished products for Christmas wreaths and garlands (Table 2).

Logs and lumber with bark

The original federal quarantine affected movement of logs and lumber with bark from all species of pine, fir (*Abies*), larch (*Larix*), and spruce (*Picea*). It was believed that logs and lumber with bark could harbor *T. piniperda* life stages beneath the bark at any time of the year. These four genera of conifers were included in the original quarantine because each was reported in Eurasia as a potential host for reproduction (Bakke 1968; USDA 1972; Speight 1980). The quarantine required that all regulated logs and lumber with bark be either completely debarked or fumigated with

Table 3. Number of *T. piniperda* interceptions on wood products (e.g. dunnage, crating, and pallets) at US ports of entry during 1985–2000 by country of origin (*Source*: USDA APHIS).

Country	Number of interceptions (1985–2000)	Number of interceptions by wood product					Imported item associated with most interceptions
		Dunnage	Crating	Pallets	Twig	Other[b]	
France	33	24	3	0	1	5	Steel
Italy	25	1	13	1	0	10	Tiles
UK	21	19	0	0	0	2	Not recorded
Spain	17	3	7	0	0	7	Tiles
Belgium	9	8	0	0	0	1	Steel
Germany	8	5	1	1	0	1	Parts
Europe	8[a]	7	0	0	0	1	Steel
Netherlands	5	1	2	0	0	2	Paper
Unknown	5	2	0	0	0	3	Not recorded
Russia	4	3	0	0	0	1	Steel
Japan	3	2	0	0	0	1	Steel
Portugal	3	0	1	0	0	2	Marble
Turkey	3	1	2	0	0	0	Marble
China	2	1	0	0	0	1	Ironware, Marble
Finland	1	1	0	0	0	0	Steel
Greece	1	0	1	0	0	0	Not recorded
Lithuania	1	1	0	0	0	0	Not recorded
Sweden	1	1	0	0	0	0	Not recorded
Switzerland	1	0	1	0	0	0	Machinery
Total	151	80	31	2	1	37	

[a]These eight interceptions were on cargo that originated in Europe, but no individual country of origin could be identified.
[b]Interceptions listed as 'other' were either not reported or described only as 'wood.'

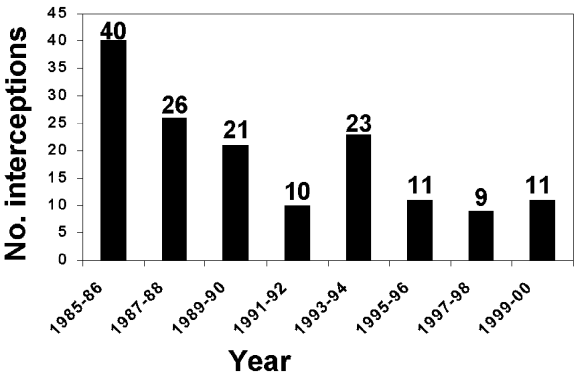

Figure 2. Number of *T. piniperda* interceptions at US ports of entry at 2-year intervals during 1985–2000; total = 151 interceptions.

methyl bromide before being transported from regulated to unregulated areas. For practical and economic reasons these two options were not acceptable to the logging industry and therefore movement of logs with bark from regulated areas to mills in unregulated areas essentially stopped.

In January 1993, APHIS sponsored a 'Science Panel' meeting in Washington, DC, in which expert testimony was presented by two European forest entomologists: Dr Alf Bakke of Norway and Dr Bo Långström of Sweden (Haack 1997). These two European experts addressed many aspects of *T. piniperda* biology and control, including reproduction in non-pine conifers. They stated that although *T. piniperda* can reproduce in fir, larch, and spruce, such behavior occurs only occasionally, and that pine is by far the preferred host. Based largely on this expert testimony, APHIS removed fir, larch, and spruce logs and lumber as regulated articles later in 1993 (Table 2). Nevertheless, in subsequent free-choice field studies conducted in Michigan, some *T. piniperda* adults attacked and their progeny completed development in logs of tamarack (*Larix laricina* (Du Roi) K. Koch), spruce (*Picea glauca* (Moench) Voss, and *Picea pungens* Engelm.), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) (Haack et al., unpublished data). Although development in non-pine conifers has been confirmed in field studies in the US, pine continues to be the only regulated genus of trees in the US since 1993.

Another major change that occurred to the quarantine in 1993 was the allowance for free movement of pine logs and lumber with bark from regulated to unregulated areas if the trees were felled and shipped during July through October (Table 2). This new regulation

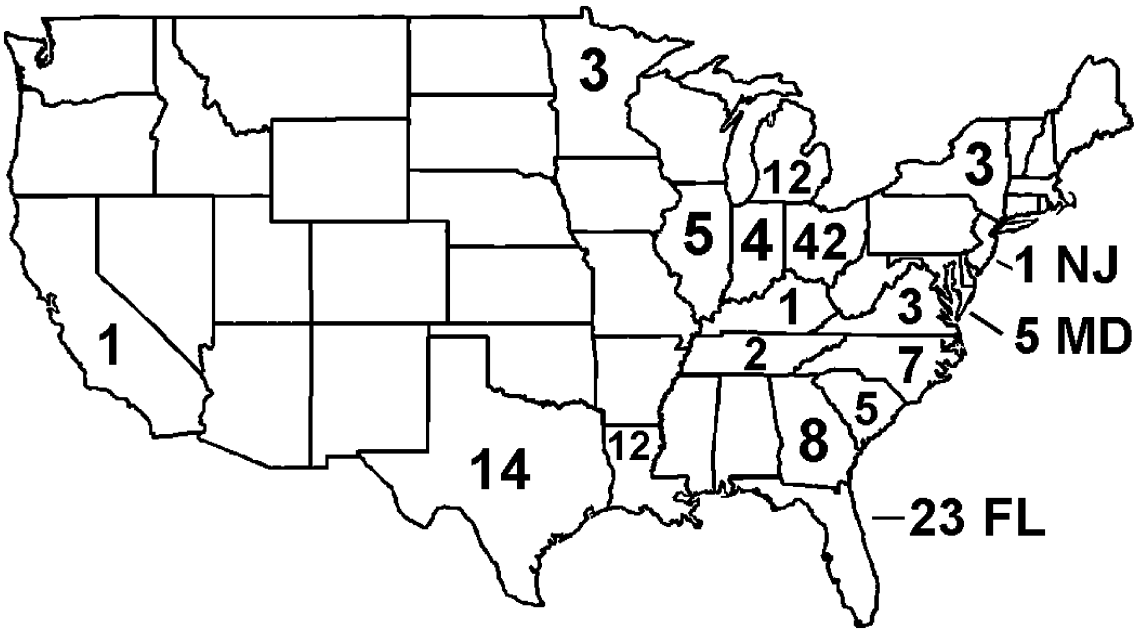

Figure 3. Number of *T. piniperda* interceptions at US ports of entry during 1985–2000 by state; total = 151 interceptions.

Table 4. Number of *T. piniperda* interceptions on wood products at US ports of entry during 1985–2000 and the two most common countries of origin (in decreasing order) by month of year when the interception occurred (*Source*: USDA APHIS).

Month	Number of interceptions (1985–2000)	Top two countries of origin
January	1	Italy
February	12	Italy, Spain
March	8	Italy, Spain
April	11	Italy, Spain
May	12	France, Belgium
June	25	France, Spain
July	39	France, UK
August	14	France, Germany
September	7	UK, France
October	11	UK, France
November	8	UK, France
December	3	Italy, Spain

also required that all branches and foliage be removed from the logs and left at the harvest site, given that during these 4 months of summer and early autumn nearly all *T. piniperda* individuals are shoot-feeding adults. Therefore, if all branches and foliage remained at the harvest site, there would be minimal risk of transporting *T. piniperda* to uninfested areas in logs from the newly felled trees. This change was welcomed by the logging industry because it established a 4-month window when pine logs could be transported from regulated to unregulated areas without first debarking or fumigating the logs. As *T. piniperda* continues to expand its range in the US, APHIS will need to modify the starting and ending dates for this window given the wide climatic variability in the US (Figure 4). For example, the current 4-month window could be lengthened as *T. piniperda* moves further south in the US, but the window should be shortened as *T. piniperda* moves northward.

Since 1993, there have been several attempts to further modify the logging regulations, especially for the period November through June when logs or lumber with bark cannot be moved outside the regulated area unless first debarked or fumigated (Haack 1997; Haack et al. 1997). One scenario that was considered divided the year into three time periods. During July through September, movement of newly harvested pine logs would be unrestricted, given that *T. piniperda* adults would be shoot feeding during these months. During October through April, movement of newly harvested pine logs to approved mills would be allowed if all slabs or bark from those logs were treated or destroyed before the end of April. During this period, most adults would be overwintering. However, during March and April, some reproduction could occur, but it was generally thought that most adults would remain in the millyard

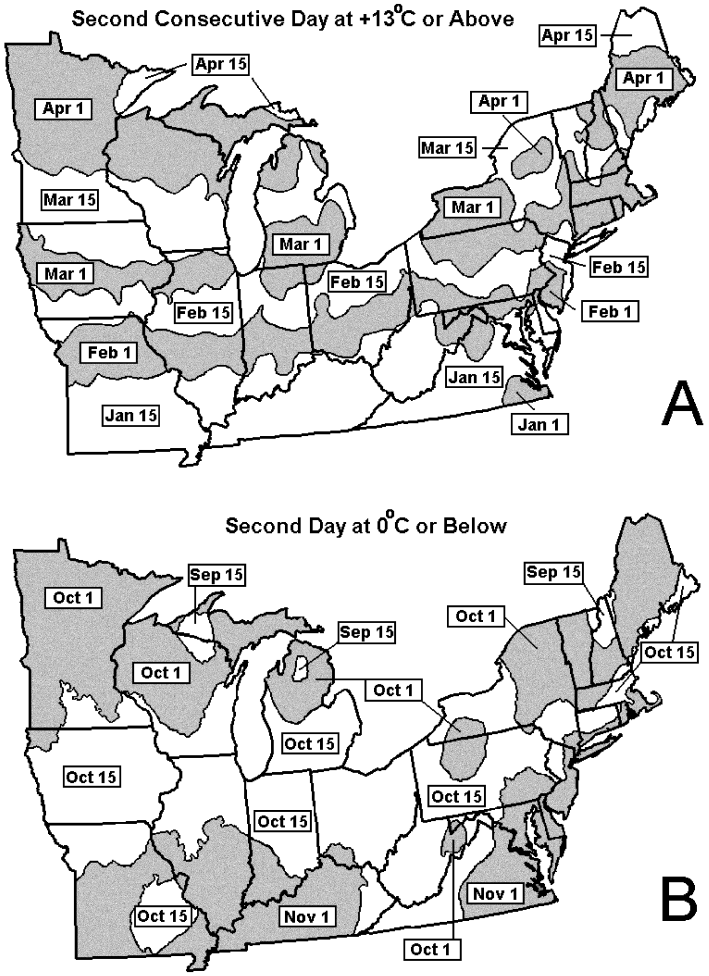

Figure 4. Isopleths at approximate 15-day intervals for (A) the average date in spring when the daily maximum temperature first reached 13 °C or warmer on two consecutive days, which approximates the timing of initial spring flight of *T. piniperda* and (B) the average date in autumn when the daily minimum temperature reached 0 °C or colder for the second time, which approximates the timing of initial shoot departure in autumn. Isopleths were developed from the 1950 to 1993 daily maximum and minimum temperature records from 824 reporting stations in a 23-state region of the northeastern US (see Haack et al. 1998).

and thus by processing all logs by the end of April, destruction of any developing brood would be ensured (Poland et al. 2000). During May and June, movement of newly harvested pine logs to approved mills would be allowed if all slabs or bark from those logs were treated or destroyed within four weeks of harvesting. Considering that brood development requires more than four weeks, this regulation would ensure that the logs and bark are processed prior to any emergence by brood adults. Although the logging regulations in the federal quarantine have not been modified since 1993, some individual mills in *T. piniperda*-free areas have developed their own individual compliance agreements with APHIS and their particular state Department of Agriculture that allow importing of barked logs from regulated areas. Mills are often eager to enter such agreements when they are located in a *T. piniperda*-free area but much of the timber they purchase is located in regulated (infested) areas.

Pine stumps

Stumps from recently cut pine trees were added as a regulated article in 1993 (Table 2). Pine stumps are occasionally harvested and used to generate fuel and turpentine. Stumps were added because they could

harbor overwintering adults in winter or serve as breeding material in spring and early summer. Stumps from regulated areas could be moved if fumigated with methyl bromide. In addition, stumps, like logs, could be moved freely from regulated to unregulated areas if the stumps were from trees cut during July through October and shipped during that same period. Again, like with logs, APHIS will need to alter the starting and ending dates for this shipping window, depending on local climatic conditions as *T. piniperda* continues to expand its range.

Pine bark

Pine bark, in the form of nuggets and chips, was added as a regulated article in 1993 (Table 2). Pine bark is commonly burned to generate energy or used in the landscape industry as a ground cover. Pine bark was added because it was learned that some life stages, especially adults, could survive the debarking process and thus could be transported with the bark. *Tomicus piniperda* life stages could be present under or inside the bark of trees cut in fall, winter, and spring. The quarantine allowed bark to be moved to areas outside the regulated area if first fumigated with methyl bromide. APHIS did not establish an open season for free movement of bark similar to that implemented for logs, lumber, and stumps. Moreover, APHIS treated all types of pine bark equally, no matter its age, size, or whether it had been mulched at elevated temperatures. Research is currently underway to establish proper guidelines for chipping, mulching, and storing of bark as an alternative to fumigation.

Pine Christmas trees

Pine Christmas trees were regulated in the original quarantine in 1992 (Table 2). About 35 million Christmas trees were sold in the US in 1999, with about 40% of the production coming from the 12 states that are currently infested with *T. piniperda* (USDA NASS 1999). In Michigan alone, 3–5 million Christmas trees are cut annually and shipped to more than 40 other states; about 50–60% of the Christmas trees harvested in Michigan are Scotch pine (Koelling et al. 1992; USDA NASS 1999). Practically every producer in the infested area who grows pine Christmas trees for the wholesale market is impacted by the quarantine, because some portion of their trees will be sold to markets outside the quarantine zone (Riessen 1997).

In 1992, the federal quarantine required that all pine Christmas trees must either pass inspection or be fumigated before shipment to areas outside the quarantine zone (Table 2). In 1993, APHIS approved a cold treatment option and modified the fumigation option for pine Christmas trees (Table 2). However, due to the added costs, potential damage to foliage, and inconvenience of subjecting Christmas trees to either cold treatment or fumigation, practically all producers selected the inspection option.

The inspection protocol required random selection and inspection of a specified number of pine trees based on the total number of pine trees being harvested from a particular field (USDA APHIS 1992). If one or more *T. piniperda* adults or *T. piniperda*-attacked shoots are found during the inspection, all pine trees from that particular field are restricted. Pine trees from restricted fields can only be sold in areas already known to be infested with *T. piniperda*, unless the producer subjects the trees to cold treatment or fumigation.

Pine nursery stock

The original 1992 quarantine prohibited all movement of pine nursery stock unless the plants were less than 24 inches tall (Table 2). In 1993, the quarantine was changed to allow free movement of pine nursery stock if the plants were less than 36 inches tall and less than 1 inch in stem diameter at ground line. For taller pine nursery stock, plants could be shipped on an individual basis if (a) found to be free of *T. piniperda* after a complete branch-by-branch inspection, or if (b) subjected to an approved cold treatment. An ‘open season’ for shipping pine nursery stock in spring without inspection or treatment was desired by the nursery industry. At first it was thought possible that nursery stock would be free of *T. piniperda* adults starting sometime after initiation of spring flight of the overwintering adults and then ending sometime before initiation of shoot feeding by the progeny adults. However, based on studies in Europe (Salonen 1973; Långström 1983) and the US (Haack et al. 2000b), no such period exists given that some parent adults can be found shoot feeding at any time during spring.

Pine wreaths and garlands

In 1995, APHIS added pine wreaths and garlands, including both the raw materials and the finished products, to the list of regulated articles (Table 2). These

items were added because it was believed that some shoot-feeding *T. piniperda* adults could still be present when the shoots were collected and thus there was some risk that *T. piniperda* could move with the cut shoots and possibly even with the finished products. Cold treatment and fumigation were offered as treatment options. Later in 1999, APHIS proposed to remove finished wreaths and garlands from the list of regulated articles, and in 2000 this ruling became final (Table 2). APHIS made this change based largely on the belief that producers would avoid using discolored or injured shoots when manufacturing wreaths and garlands and therefore the finished products would pose minimal risk of spreading *T. piniperda*.

Compliance management program

Wholesale Christmas tree producers within the regulated area found the quarantine difficult to work with because they usually sign contracts to sell their trees during June and July but the inspections would not typically occur until October (Riessen 1997). Therefore, a single *T. piniperda* adult or damaged shoot found during the October inspection could make it impossible for producers to fulfill their contracts. Under such circumstances, both producers and buyers could suffer economic losses. Given this situation, Christmas tree producers understandably requested that APHIS consider development of additional options. In response to this request, scientists and regulators worked together to develop the 'Pine Shoot Beetle Compliance Management Program' (USDA APHIS 1996) for both pine Christmas trees and pine nursery stock. Several studies were conducted, including extensive field testing in Indiana and Michigan (McCullough and Sadof 1998). Through a series of meetings and workshops, researchers shared the early results of their studies. This high level of cooperation among scientists and regulators was critical to the successful development of the compliance program. Many studies that address aspects of the compliance program have been published (Haack and Lawrence 1995a,b, 1997a,b; McCullough and Smitley 1995; Lawrence and Haack 1995; McCullough and Sadof 1996, 1998; Haack et al. 1998, 2000a,b, 2001; Kauffman et al. 1998; McCullough et al. 1998), while many others still await formal publication. The compliance management program was released for public comment in August 1996 (USDA APHIS 1996), and the original version is available on the internet (http://www.ceris.purdue.edu/napis/pests/psb/freg/psbfinal.txt).

The pine shoot beetle compliance management program is a voluntary program sponsored by APHIS and the National Plant Board, but managed by the state regulatory agency within each infested state. Producers can elect to enroll in the program or they can select inspection or any of the other treatment options. Briefly, the program requires producers to conduct a series of management protocols throughout the production cycle of the trees (McCullough and Sadof 1996, 1998; USDA APHIS 1996). The required protocols include (1) destruction of all potential brood material by specified dates, (2) trapping of parent adults in spring with trap logs, (3) insecticide applications to foliage, trunks, or stumps when specified conditions occur, (4) monitoring of trees for evidence of *T. piniperda* shoot feeding, and (5) record keeping of all pertinent information. Producers must allow state regulatory officials to inspect their trees and records at any time to make sure that all required steps are followed.

As first envisioned, this program would have allowed producers in regulated areas to ship their trees to unregulated areas without any mandatory pre-shipment inspection if the producers followed all required program guidelines. The rationale for this program was the belief that if all pest management steps were followed, then the resulting *T. piniperda* population would be very low or undetectable. Therefore, shipping trees from areas that were managed according to the program guidelines would pose only minimal risk of introducing *T. piniperda* into new areas. Christmas tree producers, especially those with large wholesale operations, welcomed the compliance management program because they felt confident that they would be able to ship their trees as long as they completed all requirements of the compliance program. However, when the program was actually implemented, most infested states continued to conduct pre-shipment inspections.

The pine shoot beetle compliance management program was initiated in 1997. More than 100 Christmas tree producers in five states enrolled in the program in 1997: 14 producers in Indiana, 80 in Michigan, 12 in Ohio, and 1 in Pennsylvania. However, as of 2000, only about 50 producers remained enrolled in the program: 9 producers in Indiana, 28 in Michigan, 2 in New York, and 12 in Ohio. After working under the compliance program for one or two years, many producers felt comfortable switching back to the autumn inspection

option given that (a) their local *T. piniperda* populations were relatively low and thus they had little or no *T. piniperda*-associated damage, (b) they currently used good cultural and chemical control practices for other tree pests that also served to suppress *T. piniperda* when present, (c) the requirements of the compliance program were relatively costly and strict, and (d) most of the infested states insisted on conducting pre-shipment inspections whether or not the producer was enrolled in the program.

Some modifications to the compliance program have been made, such as allowing each state to set its own dates for specific management guidelines based on local climatic conditions (Figure 4), and more changes will occur as needed. Although producers have been enrolled in the program since 1997, APHIS has not yet formally published the compliance management program in the US Federal Register.

Biological control efforts

During the mid-1990s, classical biological control was actively considered by APHIS as part of the overall regional suppression program for *T. piniperda* in the US, especially in forested areas where active pest suppression using cultural and chemical controls was not practical or economical (Haack and Lawrence 1997a; Haack et al. 1997). In the Great Lakes region, *T. piniperda* typically initiates spring flight about 3–6 weeks earlier than the principal native pine-infesting bark beetles and their associated natural enemies and thus faces little initial interspecific competition and natural enemy pressure (Haack and Lawrence 1995a,b, 1997a). Given this finding, USDA entomologists looked to Eurasia for natural enemies that were better synchronized with the early spring flight of *T. piniperda*. The general consensus reached by APHIS after consulting the literature and several Eurasian forest entomologists was that the predatory clerid beetle *Thanasimus formicarius* (L.) was the best candidate because (1) its threshold temperature for flight closely matches that of *T. piniperda*, (2) it is attracted to host volatiles such as alpha-pinene, (3) it is commonly associated with *T. piniperda* throughout Eurasia, and (4) it causes high levels of *T. piniperda* mortality (Schroeder 1988, 1996; Schroeder and Weslien 1994; Herard and Mercadier 1996).

A cooperative effort to evaluate *T. formicarius* for possible release in the US was initiated in 1995 among three USDA agencies: APHIS, Forest Service, and Agricultural Research Service (Haack et al. 1997). Several hundred *T. formicarius* adults were collected in France in 1995 and 1996 and shipped to three USDA laboratories in the US where rearing techniques were developed and studies were conducted on potential non-target impacts of *T. formicarius* on the common North American clerid *Thanasimus dubius* (F). Results of these laboratory studies suggested that *T. formicarius* would not competitively displace *T. dubius* (Haack et al., unpublished data). In 1996, state Department of Agriculture officials within the *T. piniperda*-infested states voted to postpone the release of *T. formicarius* indefinitely. The two main reasons given for this decision were (1) that *T. piniperda* had not yet caused significant levels of damage to the pine resource to justify release and (2) there was continued concern over potential non-target impacts of releasing this exotic predator, which feeds on many species of bark beetles, including possible direct effects on other natural enemies and indirect effects on the outbreak dynamics of native bark beetles (Haack et al. 1997).

Extension and research efforts

Extension and research efforts on *T. piniperda* were initiated in the US in 1992. Pest alerts (e.g. Haack and Kucera 1993), inspection manuals (USDA APHIS 1993), compliance management program manuals (McCullough and Sadof 1996) and Web sites (e.g. http://www.ceris.purdue.edu/napis/pests/psb/) were produced and widely distributed. Research was conducted primarily by USDA APHIS, and USDA Forest Service at the federal level, and by several US universities such as Michigan State University, Ohio State University, Portland State University, Purdue University, State University of New York-Syracuse, University of Georgia, University of Vermont, and University of Wisconsin. In addition, several other state, industrial, private, and professional organizations contributed time, funding, plant material, and equipment. In Canada, research and monitoring efforts were led by the Canadian Forest Service, Canadian Food Inspection Agency, Ontario Ministry of Natural Resources, Quebec Department of Natural Resources, and the University of Toronto.

Research efforts in North America have addressed many aspects of *T. piniperda* biology and management, including timing of initial spring flight (Haack

and Lawrence 1995b, Haack et al. 1998), adult dispersal behavior (Barak et al. 2000; Poland and Haack 2000a), influence of tree felling date on subsequent colonization (Haack and Lawrence 1995a), reproductive biology and brood production (Ryall and Smith 1997; Poland et al. 2000), chemical ecology and trapping (Haack and Lawrence 1997a; Czokajlo and Teale 1999; Poland and Haack 2000b), reproduction and shoot feeding in native pines (Sadof et al. 1994; Lawrence and Haack 1995; Ryall and Smith 2000; Siegert and McCullough 2001), seasonal shoot-feeding behavior (Haack et al. 2000b), impact of shoot feeding (Czokajlo et al. 1997; Siegert 2000), foliar chemical control (McCullough and Smitley 1995), chemical control for logs and stumps (McCullough et al. 1998), control through burial of brood logs (Haack et al. 2000a), timing of autumn shoot departure and overwintering behavior (Haack et al. 1998, 2001; Kauffman et al. 1998; Petrice et al. 2002), adult survival in cut Christmas trees (Haack and Lawrence 1997b), DNA analysis of various *T. piniperda* populations in the US (Carter et al. 1996), natural enemies (Bright 1996; Kennedy 1998), early history of *T. piniperda* in North America (Haack 1997; Haack et al. 1997), and the compliance management program (McCullough and Sadof 1996, 1998). Many other studies still await publication or are in progress.

In addition, many areas of research have not been addressed to date, such as measuring the ecological effects of the invasion process (Parker et al. 1999). For example, to what degree has the presence of *T. piniperda* altered the genetics, population dynamics, and community structure of the native pine-infesting bark beetles and associated natural enemies? Could the presence of an early season bark beetle like *T. piniperda* cause a genetic shift in the natural enemy complex so that some predators or parasitoids lower their flight threshold temperature to more closely match *T. piniperda*? Similarly, could the fact that *T. piniperda* is now the first or among the first subcortical insect to colonize recently dead or dying pine trees, logs, and stumps in spring alter the species richness and outbreak dynamics of the native bark beetles and other subcortical insects?

Impact of *T. piniperda* in North America

To date, *T. piniperda* has caused relatively little damage to pine Christmas trees growing in well-managed fields (Riessen 1997; McCullough and Sadof 1998), or to pine trees growing in natural or planted forest stands throughout the infested portions of North America. Nevertheless, severe damage, including tree mortality, has been reported in unmanaged Scotch pine forest plantations in New York State (Czokajlo et al. 1997) and in southwestern Ontario (Scarr et al. 1999). In these two cases, *T. piniperda* populations had already reached damaging levels at the time of their discovery and therefore it was not clear as to what circumstances led to the population buildups. In both areas, shoot feeding was so severe that several of the weakened trees were attacked and killed by *T. piniperda* during its spring reproductive phase.

The ability of *T. piniperda* to weaken trees through successive years of severe shoot feeding and subsequently utilize them for breeding has been documented in other world regions, such as southwestern China (Ye 1991). To what degree *T. piniperda* will be a significant threat to North American forestry is still unknown. Nevertheless, *T. piniperda* will certainly continue to spread throughout North America given that it can shoot-feed and reproduce in several species of North American pines (Sadof et al. 1994; Långström et al. 1995; Lawrence and Haack 1995; Haack and Lawrence 1997; Ryall and Smith 2000; Siegert and McCullough 2001), it is among the first pine-infesting scolytids to become active in spring (Haack and Lawrence 1995a,b; Kennedy 1998), and it readily breeds in pine logging slash and stumps as well as live trees severely weakened by wind, snow, ice, fire, drought, and defoliation (Långström 1984; Ye 1991; Eidmann 1992; Schroeder and Eidmann 1993; Annila et al. 1999; Fernandez and Costas 1999)

Future prospects

When APHIS established the *T. piniperda* federal quarantine in November 1992, it was with the belief that *T. piniperda* was a highly destructive pest of pines. In the USDA series on 'Insects Not Known to Occur in the United States', *T. piniperda* was described as an important pest that could reach outbreak levels quickly and devastate pine forests (USDA 1972). In July 1992, the USDA Forest Service (1992) prepared a pest risk assessment of *T. piniperda* at the request of APHIS. In that assessment, *T. piniperda* was ranked as a high risk pest with potential economic losses estimated at $861 million over 30 years. Given such reports, it

is understandable why APHIS acted to establish the quarantine soon after the insect's discovery. Nevertheless, except for the two cases mentioned above (Czokajlo et al. 1997; Scarr et al. 1999), there have been no other documented cases to date of severe growth loss or mortality to pines in North America that could be attributed to *T. piniperda*.

In recent years, APHIS has begun to reevaluate the *T. piniperda* quarantine given (a) the high economic impacts to the affected pine industries and individual producers, (b) the high program costs of the compliance management program, (c) the relatively low level of damage to pines in the infested states, (d) the uncertain level of damage or impact that *T. piniperda* would cause if it spread to the southern or western regions of the US, and (e) the continued natural spread of the beetle regardless of the quarantine (USDA APHIS 2000). In 2000, APHIS completed a new pest risk assessment of *T. piniperda* in which this beetle was ranked as a medium risk pest (USDA APHIS 2000). In addition, in 2000, APHIS requested public comment on the future of the quarantine (Table 2). Out of 18 written responses to this request (letters on file with USDA APHIS, Riverdale, Maryland, Docket No. 00-058-1), 13 favored continuation of the quarantine and 5 opposed it. The two main reasons given in support were (1) the belief that *T. piniperda* remains a significant threat to the southern and western pines and that the quarantine serves as an effective safeguard against human-assisted spread, and (2) the current quarantine provides a uniform set of regulations for the entire country. In contrast, reasons given for eliminating the quarantine varied widely. One group stated that *T. piniperda* was an insignificant pest and thus no quarantine was warranted, while another group believed that the current quarantine was not strict enough and therefore should be dropped so that uninfested states could impose stricter regulations on the infested states. Given such variation in responses, it is clear that federal regulatory agencies like APHIS face a difficult challenge when attempting to balance the economic concerns and resource protection needs of infested and uninfested regions within their borders. Moreover, the above situation demonstrates that it is difficult for agencies like APHIS to change course once they have enacted a federal quarantine given that the concerns of the uninfested states have been heightened by the initial establishment of the quarantine. As mentioned earlier, if the federal quarantine on *T. piniperda* were dropped, each uninfested US state could enact its own state-level quarantine on pine products from the infested states. After considering the above public comments, APHIS decided in March 2001 to maintain for now the domestic quarantine on *T. piniperda*.

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References

Annila E, Långström B, Varama M, Hiukka R and Niemela P (1999) Susceptibility of defoliated Scots pine to spontaneous and induced attack by *Tomicus piniperda* and *Tomicus minor*. Silva Fennica 33:93–106

Bakke A (1968) Ecological studies on bark beetles (Coleoptera: Scolytidae) associated with Scots pine (*Pinus sylvestris* L.) in Norway with particular reference to the influence of temperature. Meddelelser fra Det Norske Skogforsoksvesen 21(83): 443–602

Barak AV, McGrevy D and Tokaya G (2000) Dispersal and recapture of marked, overwintering *Tomicus piniperda* (Coleoptera: Scolytidae) from Scotch pine bolts. Great Lakes Entomologist 33: 69–80

Bright DE (1996) Notes on native parasitoids and predators of the larger pine shoot beetle, *Tomicus piniperda* (Linnaeus) in the Niagara region of Canada (Coleoptera: Scolytidae). Proceedings of the Entomological Society of Ontario 127: 57–62

Carter MCA, Robertson JL, Haack RA, Lawrence RK and Hayes JL (1996) Genetic relatedness of North American populations of *Tomicus piniperda* (Coleoptera: Scolytidae). Journal of Economic Entomology 89: 1345–1353

Czokajlo D and Teale SA (1999) Synergistic effect of ethanol to a-pinene in primary attraction of the larger pine shoot beetle, *Tomicus piniperda*. Journal of Chemical Ecology 25: 1121–1130

Czokajlo D, Wink RA, Warren JC and Teale SA (1997) Growth reduction of Scots pine, *Pinus sylvestris*, caused by the larger pine shoot beetle, *Tomicus piniperda* (Coleoptera: Scolytidae), in New York state. Canadian Journal of Forest Research 27: 1394–1397

Eidmann HH (1992) Impact of bark beetles on forests and forestry in Sweden. Journal of Applied Entomology 114: 193–200

Fernandez MMF and Costas JMS (1999) Susceptibility of fire-damaged pine trees (*Pinus pinaster* and *Pinus nigra*) to attacks by *Ips sexdentatus* and *Tomicus piniperda* (Coleoptera: Scolytidae). Entomologia Generalis 24: 105–114

Haack RA (1997) Early history and spread of *Tomicus piniperda* in North America. In: 1997 Japanese Beetle and the Pine Shoot Beetle Regulatory Review: Proceedings, pp 146–153. Louisville,

Kentucky, USA, 24–26 February 1997, USDA Animal and Plant Health Inspection Service, Riverdale, Maryland

Haack RA and Cavey JF (2000) Insects intercepted on solid wood packing materials at United States ports-of-entry: 1985–1998. In: Proceedings: International Conference on Quarantine Pests for the Forestry Sector and Their Effects on Foreign Trade, Concepcion, Chile, 27–28 June 2000. CORMA, Concepcion, Chile, 16 pp

Haack RA and Kucera D (1993) New introduction – Common pine shoot beetle, *Tomicus piniperda* (L.). USDA Forest Service, Northeastern Area, Pest Alert NA-TP-05-93. 2 pp

Haack RA and Lawrence RK (1995a) Attack densities of *Tomicus piniperda* and *Ips pini* (Coleoptera: Scolytidae) on Scotch pine logs in Michigan in relation to felling date. Journal of Entomological Science 30: 18–28

Haack RA and Lawrence RK (1995b) Spring flight of *Tomicus piniperda* in relation to native Michigan pine bark beetles and their associated predators. In: Hain FP, Payne TL, Raffa KF, Salom SM and Ravlin FW (eds) Proceedings: Behavior, Population Dynamics and Control of Forest Insects, pp 524-535. Maui, Hawaii, USA, 6–11 February 1994, Ohio State University Press, Columbus, Ohio

Haack RA and Lawrence RK (1997a) Highlights of Forest Service research on *Tomicus piniperda*: 1992–1996. In: 1997 Japanese Beetle and the Pine Shoot Beetle Regulatory Review: Proceedings, pp 115–122. Louisville, Kentucky, USA, 24–26 February 1997, USDA Animal and Plant Health Inspection Service, Riverdale, Maryland

Haack RA and Lawrence RK (1997b) *Tomicus piniperda* (Coleoptera: Scolytidae) reproduction and behavior on Scotch pine Christmas trees taken indoors. Great Lakes Entomologist 30: 19–31

Haack RA, Lawrence RK, McCullough DG and Sadof CS (1997) *Tomicus piniperda* in North America: an integrated response to a new exotic scolytid. In: Gregoire JC, Liebhold AM, Stephen FM, Day KR and Salom SM (eds) Proceedings: Integrating Cultural Tactics into the Management of Bark Beetle and Reforestation Pests, pp 62–72. Vallombrosa, Italy, 1-4 September 1996, USDA Forest Service, General Technical Report NE-GTR-236

Haack RA, Poland TM and Heilman WE (1998) Using historical temperature records to adjust the federal quarantine of the pine shoot beetle. In: Proceedings of the 13th Conference on Biometeorology and Aerobiology, pp 319–322. Albuquerque, New Mexico, USA, 2–6 November 1998, American Meteorological Society, Boston, Massachusetts

Haack RA, Petrice TR and Poland TM (2000a) *Tomicus piniperda* (Coleoptera: Scolytidae) emergence in relation to burial depth of brood logs. Journal of Economic Entomology 93: 242–246

Haack RA, Lawrence RK and Heaton GC (2000b) Seasonal shoot-feeding by *Tomicus piniperda* (Coleoptera: Scolytidae) in Michigan. Great Lakes Entomologist 33: 1–8

Haack RA, Lawrence RK and Heaton GC (2001) *Tomicus piniperda* (Coleoptera: Scolytidae) shoot-feeding characteristics and overwintering behavior in Scotch pine Christmas trees. Journal of Economic Entomology 94: 422–429

Herard F and Mercadier G (1996) Natural enemies of *Tomicus piniperda* and *Ips acuminatus* (Col., Scolytidae) on *Pinus sylvestris* near Orleans, France: temporal occurrence and relative abundance, and notes on eight predatory species. Entomophaga 41: 183–210

Hoebeke ER (1994) New records of immigrant bark beetles (Coleoptera: Scolytidae) in New York: attraction of conifer-feeding species to ethanol-baited trap logs. Entomological News 105: 267–276

Hoebeke ER (2001) *Hylurgus ligniperda*: a new exotic pine bark beetle in the United States. Newsletter of the Michigan Entomological Society 46: 1–2

Kauffman WC, Waltz RD and Cummings RB (1998) Shoot feeding and overwintering behavior of *Tomicus piniperda* (Coleoptera: Scolytidae): implications for management and regulation. Journal of Economic Entomology 91: 182–190

Kennedy AA (1998) Interactions of the pine shoot beetle (*Tomicus piniperda* (L.) (Coleoptera: Scolytidae)) with native pine bark beetles and their associated natural enemies in Michigan. MS thesis, Department of Entomology, Michigan State University, East Lansing, Michigan, 151 pp

Koelling MR, Hart JB and Leefers L (1992) Christmas tree production in Michigan. Michigan State University, Agricultural Experiment Station, East Lansing, Michigan, USA, Special Report 61

Långström B (1983) Life cycles and shoot-feeding of the pine shoot beetles. Studia Forestalia Suecica 163: 1–29

Långström B (1984) Windthrown Scots pines as brood material for *Tomicus piniperda* and *T. minor*. Silva Fennica 18: 187–198

Långström B, Lieutier F, Hellqvist C and Vouland G (1995) North American pines as hosts for *Tomicus piniperda* (L.) (Col., Scolytidae) in France and Sweden. In: Gregoire JC, Liebhold AM, Stephen FM, Day KR and Salom SM (eds) Proceedings: Integrating Cultural Tactics into the Management of Bark Beetle and Reforestation Pests, pp 547–557. Vallombrosa, Italy, 1–4 September 1996, USDA Forest Service, General Technical Report NE-GTR-236

Lawrence RK and Haack RA (1995) Susceptibility of selected species of North American pines to shoot-feeding by an Old World scolytid: *Tomicus piniperda*. In: Hain FP, Payne TL, Raffa KF, Salom SM and Ravlin FW (eds) Proceedings: Behavior, Population Dynamics and Control of Forest Insects, pp 536–546. Maui, Hawaii, USA, 6–11 February 1994, Ohio State University Press, Columbus, Ohio

Liebhold AM, Macdonald WL, Bergdahl D and Mastro VC (1995) Invasion by exotic forest pests: a threat to forest ecosystems. Forest Science Monograph 41: 1–49

Mattson WJ, Niemela P, Millers I and Inguanzo Y (1994) Immigrant phytophagous insects on woody plants in the United States and Canada: an annotated list. USDA Forest Service, North Central Forest Experiment Station, St Paul, Minnesota, General Technical Report NC-169, 27 pp

McCullough DG and Sadof CS (1996) Pine shoot beetle compliance program for Christmas trees: a manual for Christmas tree growers. Michigan State University Extension, East Lansing, Michigan, USA. Extension Bulletin E-2615, 15 pp

McCullough DG and Sadof CS (1998) Evaluation of an integrated management and compliance program for *Tomicus piniperda* (Coleoptera: Scolytidae) in pine Christmas tree fields. Journal of Economic Entomology 91: 785–795

McCullough DG and Smitley DR (1995) Evaluation of insecticides to reduce maturation feeding by *Tomicus piniperda* (Coleoptera: Scolytidae) in Scotch pine. Journal of Economic Entomology 88: 693–699

McCullough DG, Haack RA and McLane WH (1998) Control of *Tomicus piniperda* (Coleoptera: Scolytidae), in pine stumps and logs. Journal of Economic Entomology 91: 492–499

Niemela P and Mattson WJ (1996) Invasion of North American forests by European phytophagous insects. BioScience 46: 741–753

Parker IM, Simberloff D, Lonsdale WM, Goodell K, Wonham M, Kareiva PM, Williamson MH, Von Holle B, Moyle PB, Byers JE and Goldwasser L (1999) Impact: toward a framework for understanding the ecological effects of invaders. Biological Invasions 1: 3–19

Petrice TR, Haack RA and Poland TM (2002) Selection of overwintering sites by *Tomicus piniperda* (Coleoptera: Scolytidae) during fall shoot departure. Journal of Entomological Science 37: 48–59

Poland TM and Haack RA (2000a) *Tomicus piniperda* (Coleoptera: Scolytidae): Is shoot-feeding required for reproductive maturation? Great Lakes Entomologist 33: 9–15

Poland TM and Haack RA (2000b) Pine shoot beetle, *Tomicus piniperda* (Coleoptera: Scolytidae), responses to green leaf volatiles. Journal of Applied Entomology 124: 63–69

Poland TM, Haack RA, Petrice TR, Sadof C and Onstad D (2000) Dispersal of *Tomicus piniperda* (Coleoptera: Scolytidae) from operational and simulated millyards. The Canadian Entomologist 132: 853–866

Riessen GA (1997) Pine shoot beetle: a grower's perspective. In: 1997 Japanese Beetle and the Pine Shoot Beetle Regulatory Review: Proceedings, pp 123–128. Louisville, Kentucky, USA, 24–26 February 1997, USDA Animal and Plant Health Inspection Service, Riverdale, Maryland

Ryall KL and Smith SM (1997) Intraspecific larval competition and brood production in *Tomicus piniperda* (L.) (Col., Curculionidae, Scolytinae). Proceedings of the Entomological Society of Ontario 128: 19–26

Ryall KL and Smith SM (2000) Brood production and shoot feeding by *Tomicus piniperda* (Coleoptera: Scolytidae). The Canadian Entomologist 132: 939–949

Sadof CS, Waltz RD and Kellam CD (1994) Differential shoot feeding by adult *Tomicus piniperda* (Coleoptera: Scolytidae) in mixed stands of native and introduced pines in Indiana. Great Lakes Entomologist 27: 223–228

Salonen K (1973) On the life cycle, especially on the reproduction biology of *Blastophagus piniperda* L. (Col., Scolytidae). Acta Forestalia Fennica 127: 1–72

Scarr TA, Czerwinski EJ and Howse GM (1999) Pine shoot beetle damage in Ontario. In: Fosbroke SLC and Gottschalk KW (eds) Proceedings: US Department of Agriculture Interagency Research Forum on Gypsy Moth and Other Invasive Species, Annapolis, Maryland, USA, 19–22 January 1999, USDA Forest Service, General Technical Report NE-GTR-266, p 56

Schroeder LM (1988) Attraction of the bark beetle *Tomicus piniperda* and some other bark- and wood-living beetles to the host volatiles alpha-pinene and ethanol. Entomologia Experimentalis et Applicata 46: 203–210

Schroeder LM (1996) Interactions between the predators *Thanasimus formicarius* (Col.: Cleridae) and *Rhizophagus depressus* (Col.: Rhizophagidae), and the bark beetle *Tomicus piniperda* (Col.: Scolytidae). Entomophaga 41: 63–75

Schroeder LM and Eidmann HH (1993) Attacks of bark- and wood-boring Coleoptera on snow-broken conifers over a two-year period. Scandinavian Journal of Forest Research 8: 257–265

Schroeder LM and Weslien J (1994) Reduced offspring production in bark beetle *Tomicus piniperda* in pine bolts baited with ethanol and alpha-pinene, which attract antagonistic insects. Journal of Chemical Ecology 20: 1429–1444

Siegert NW (2000) Host preference and potential impact of pine shoot beetle (*Tomicus piniperda* (L.) (Coleoptera: Scolytidae)) in Michigan pine. MS thesis. Department of Forestry, Michigan State University, East Lansing, Michigan, 150 pp

Siegert NW and McCullough DG (2001) Preference of *Tomicus piniperda* (Coleoptera: Scolytidae) parent adults and shoot-feeding progeny adults for three pine species. The Canadian Entomologist 133: 343–353

Speight MR (1980) Tree pests. 2. Sycamore aphid, *Drepanosiphum platanoides* Koch. 3. Common pine shoot beetle, *Tomicus piniperda* Linnaeus. Arboricultural Journal 4: 32–33; 157–160

US Congress (1993) Harmful non-indigenous species in the United States. US Congress, Office of Technology Assessment, Washington, DC, USA, OTA-F-565

USDA (US Department of Agriculture) (1972) A bark beetle (*Tomicus piniperda* (Linnaeus)). US Department of Agriculture, Cooperative Economic Insect Report 22(16): 234–236

USDA APHIS (US Department of Agriculture, Animal and Plant Health Inspection Service) (1992) 7 CFR Part 301 – pine shoot beetle. Federal Register, 19 November 1992, 57(224): 54492–54499

USDA APHIS (1993) Pine shoot beetle program manual. US Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Washington, DC

USDA APHIS (1996) Pine shoot beetle compliance management program. USDA APHIS, Plant Protection and Quarantine, Domestic and Emergency Programs, Riverdale, Maryland, 24 pp

USDA APHIS (2000) Pine shoot beetle (*Tomicus piniperda* (L.)): pest-initiated pest risk assessment for the likelihood and consequences of spread within the continental United States. USDA APHIS, Plant Protection and Quarantine, Raleigh, North Carolina, 33 pp

USDA Forest Service (1992) Assessment of potential impacts of *Tomicus piniperda* in the United States. USDA Forest Service, State and Private Forestry, Forest Pest Management, Washington, DC, 5 pp

USDA NASS (US Department of Agriculture, National Agricultural Statistics Service) (1999) 1997 Census of Agriculture, Vol. 1, Geographic Area Series. USDA, National Agricultural Statistics Service, Washington, DC

Wood SL and Bright DE (1992) A catalog of the Scolytidae and Platypodidae (Coleoptera), Part 2: Taxonomic Index, Vol. A. Great Basin Naturalist Memoirs 13: 1–833

Ye H (1991) On the bionomy of *Tomicus piniperda* (L.) (Col., Scolytidae) in the Kunming region of China. Journal of Applied Entomology 112: 366–369