A zoogeographical analysis of the scale insect (Hemiptera, Coccoidea) fauna of Fennoscandia and Denmark

CARL-AXEL GERTSSON

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This paper presents the results of a zoogeographical analysis of the scale insects from the following countries: Sweden, Denmark, Norway and Finland. The number of species collected so far is 92 in 49 genera. The fauna is divided into the following zoogeographical groups: Palearctic, 56.5%, Holarctic, 18.5%, species from 2–3 zoogeographic regions, 10.9%. and Cosmopolitan, 14.1%. The connections between adjacent countries are also discussed.

Key words: Scale insects, Coccoidea, zoogeography, Fennoscandia, Denmark.

Carl-Axel Gertsson, Murarevägen 13, SE-227 30 Lund, Sweden.
E-mail:carlaxel.gertsson@gmail.com

Introduction

According to the Database of the Scale Insects of the World ScaleNet (Ben-Dov *et al*. 2012), there are approximately 8000 described species of scale insects worldwide. The scale insects include all members of the superfamily Coccoidea (Hemiptera: Sternorrhyncha), which consists of 49 families (Ben-Dov *et al*. 2012). They are closely related to aphids (Aphidoidea), whiteflies (Aleyrodoidea) and jumping plant lice (Psylloidea) (Gullan & Cook 2007). The size of scale insects varies from 0.5 to 35mm, but they are usually less than 5mm in length in Fennoscandia and Denmark. Some are cryptic, often resembling part of their host plant. Scale insects are phytophagous, feeding by sucking plant juices through a set of stylets. The adult female is wingless and paedomorphic, whereas the adult male in most species is alate and with no mouthparts (Kosztarab & Kozár 1988).

Thus far, the study of scale-insects in Fennoscandia and Denmark has mainly been concerned with compiling lists of species, their ecology and distribution in individual countries. Studies in zoogeography have never been presented. In other parts of the world, however, zoogeographical investigations of scale-insects have been studied by several authors. Data covering the whole of the Palearctic region was given by Bodenheimer (1934), Kozár & Drosdják (1986), Kozár (1995b), Ben-Dov (1990), the Middle-East, Ben-Dov (2011-2012), Israel, Danzig (1986), the Far-Eastern USSR, Lagowska (2001) Poland, Longo *et al*. (1999) Italy and recently Kozár (2009) the world fauna of Eriococcidae.

The number of species reported in Fennoscandia and Denmark is low, for at least two reasons. First, few studies have been conducted in this region and notwithstanding the latter, it is also likely that fewer species occur in this region at least to the north, due to climatic constrains. Therefore the results presented in this paper can only be considered as introductory.

Materials and methods

This paper presents an analysis based on the

Data base of the Scale Insects of the World (ScaleNet) (Ben-Dov *et al.* 2012), a checklist by Gertsson (2001) and several papers from Denmark (Kozarzhevskaya & Reitzel 1975), Norway (Fjelddalen 1996), Finland (Huldén & Heikinheimo 1984, Huldén 1985, Silfverberg 2012) and Sweden (Ossiannilsson 1951, 1959, Gertsson 2005, 2011a, 2011b, 2012, Gertsson & Isacsson 2012). The distributions of the species recorded from different zoogeographical regions are according to Ben-Dov *et al*. (2012), Kozár (1998, 2004, 2009) and Lagowska (2001). The subregions of the Palearctic (Euro-Siberian, Mediterranean, Irano-Turanian and Far-Eastern) are in accordance with the map of Emeljanov (1974) (Figure 1). As Lagowska (2001) has analysed, the Palearctic is divided in the following subgroups: species distributed in all three or four subregions, species distributed in two subregions and species restricted only to the Euro-Siberian region. Families, genera and species in Table 1 are listed in an alphabetical order. The nomenclature follows Ben-Dov *et al*. (2012) and for the Eriococcidae the nomenclature follows Kozár (2009). The indoor or greenhouse species living on ornamental plants are excluded in this study. These exclusions are however very roughly due to the fact that the ”greenhouse” species during the last decades have been classified roughly as ”outdoor” species. The connections between countries close to Fennocandia and Denmark were analysed by using a Venn diagram, and the degree of similarity was calculated by means of the Sørensen index (Southwood 1966).

Results

The total number of scale insect species found in Fennoscandia and Denmark is 92 in 49 genera belonging to 12 families. The most species-rich families are Pseudococcidae (28), Coccidae (23), Diaspididae (16) and Eriococcidae (12) (Tables 1–2). The highest ratios (most species per genus) are in the families Coccidae, Eriococcidae and Diaspididae (Table 2). Four genera, *Trionymus, Acanthococcus, Eulecanium* and *Diaspidiotus* are the most dominant in their diversity. These provide 22.8% of the total species number.

Based on the distribution records of the 92

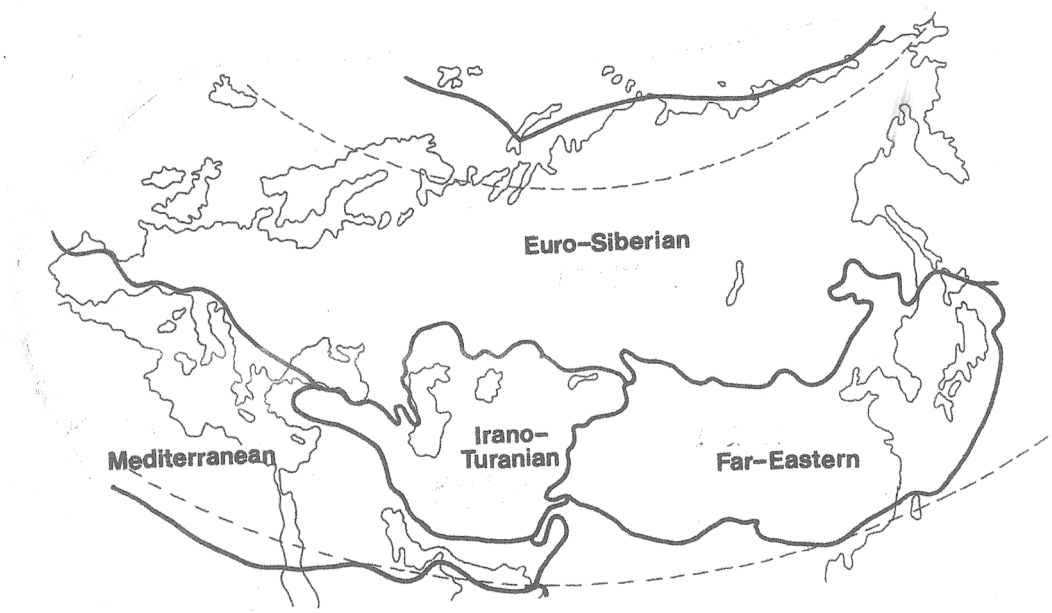

FIGURE 1. The Palearctic region and its subregions (Kozár 1995b).

TABLE 1. List of scale insects recorded from Fennoscandia and Denmark and their distribution in zoogeographical regions (Palearctic (Pal.) with following subregions Euro-Siberian (ES), Mediterranean (M), Irano-Turanian (IT), Far Eastern (FE), Nearctic (Nea.); Neotropical (Neo.); Ethiopian (Eth.); Oriental (Ori.); Australian (Aus.); and New Zealand and Pacific (NZ & P).

Species	Author	Zoogeographical regions						
		Pal. (subregions)	Nea.	Neo.	Eth.	Ori.	Aus.	NZ & P
ASTEROLECANIIDAE								
Asterodiaspis variolosa	(Ratzeburg, 1870)	Pal. (ES, M, IT, FE)	Nea.	Neo.	Eth.		Aus.	NZ & P
Planchonia arabidis	Signoret, 1877	Pal. (ES, M, IT)	Nea.	Neo.				
COCCIDAE								
Eriopeltis festucae	(Boyer de Fonscolombe, 1834)	Pal. (ES, M, IT, FE)	Nea.					
Eriopeltis lichtensteini	Signoret, 1877	Pal. (ES)						
Eriopeltis stammeri	Schmutterer, 1952	Pal. (ES, IT)						
Eulecanium ciliatum	(Douglas, 1891)	Pal. (ES, M, FE)						
Eulecanium douglasi	Sulc 1895	Pal. (ES, M, IT, FE)	Nea.					
Eulecanium franconicum	(Lindinger, 1907)	Pal. (ES, M, IT, FE)						
Eulecanium sericeum	(Lindinger, 1906)	Pal. (ES, M)						
Eulecanium tiliae	(Linnaeus, 1758)	Pal. (ES, M, IT)	Nea.			Ori.		
Lecanopsis formicarum	Newstead, 1893	Pal. (ES, M, FE)						
Luzulaspis luzulae	(Dufour, 1864)	Pal. (ES, M)						
Luzulaspis scotica	Green, 1926	Pal. (ES)						
Palaeolecanium bituberculatum	Signoret, 1873	Pal. (ES, M, IT)						
Parafairmairia gracilis	Green, 1916	Pal. (ES, M)						
Parthenolecanium corni	(Bouché, 1844)	Pal. (ES, M, IT, FE)	Nea.	Neo.		Ori.		NZ & P
Parthenolecanium fletcheri	(Cockerell, 1893)	Pal. (ES, M, IT)	Nea.					
Parthenolecanium persicae	(Fabricius, 1776)	Pal. (ES, M, IT)	Nea.	Neo.		Ori.	Aus.	NZ & P
Parthenolecanium pomeranicum	(Kawecki, 1954)	Pal. (ES, M)						
Physokermes hemicryphus	(Dalman, 1826)	Pal. (ES, M, FE)	Nea.					
Physkermes inopinatus	Danzig & Kozár, 1973	Pal. (ES)						
Physokermes piceae	(Schrank, 1801)	Pal. (ES, M)	Nea.					
Pulvinaria floccifera	(Westwood, 1870)	Pal. (ES, M, IT, FE)	Nea.	Neo.	Eth.		Aus.	NZ & P
Pulvinaria regalis	Canard, 1968	Pal. (ES)						
Pulvinaria vitis	(Linnaeus, 1758)	Pal. (ES, M, IT, FE)	Nea.	Neo.				NZ & P
DIASPIDIDAE								
Aulacaspis rosae	(Bouché, 1833)	Pal. (ES, M, IT, FE)	Nea.	Neo.	Eth.	Ori.	Aus.	NZ & P
Carulaspis juniperi	(Bouché, 1851)	Pal. (ES, M, IT)	Nea.	Neo.			Aus.	NZ & P
Carulaspis minima	(Signoret, 1869)	Pal. (ES, M, IT)	Nea.	Neo.	Eth.		Aus.	
Chionaspis salicis	(Linnaeus, 1758)	Pal. (ES, M, IT, FE)	Nea.			Ori.		
Diaspidiotus bavaricus	(Lindinger, 1912)	Pal. (ES, M)						
Diaspidiotus lenticularis	(Lindinger, 1912)	Pal. (ES, M)					Aus.	
Diaspidiotus ostreaeformis	(Curtis, 1843)	Pal. (ES, M, IT)	Nea.	Neo.		Ori.	Aus.	NZ & P
Diaspidiotus perniciosus	(Comstock, 1881)	Pal. (ES, M, IT)	Nea.	Neo.	Eth.	Ori.	Aus.	NZ & P

TABLE 1. *continued*

Species Author	Zoogeographical regions						
	Pal. (subregions)	**Nea.**	**Neo.**	**Eth.**	**Ori.**	**Aus.**	**NZ & P**
Diaspidiotus zonatus (Frauenfeld, 1868)	Pal. (ES, M, IT)						
Dynaspidiotus abietis (Schrank, 1776)	Pal. (ES, M, IT)	Nea.					
Epidiaspis leperii (Signoret, 1869)	Pal. (ES, M, IT)	Nea.	Neo.		Ori.		
Lepidosaphes conchiformis (Gmelin, 1790)	Pal. (ES, M, IT, FE)	Nea.	Neo.	Eth.	Ori.		
Lepidosaphes newsteadi Sulc, 1895	Pal. (ES, M, IT)	Nea.	Neo.				
Lepidosaphes ulmi (Linnaeus, 1758)	Pal. (ES, M, IT, FE)	Nea.	Neo.		Ori.	Aus.	NZ & P
Leucaspis lowi Colvée, 1882	Pal. (ES, M, IT)				Ori.		
Leucaspis pini (Hartig, 1839)	Pal. (ES, M, IT)						
ERIOCOCCIDAE							
Acanthococcus baldonensis Rasina, 1966	Pal. (ES)						
Acanthococcus devoniensis (Green, 1896)	Pal. (ES, M)						
Acanthococcus greeni (Newstead, 1898)	Pal. (ES, M, IT)	Nea.					
Acanthococcus timidus (Huldén, 1985)	Pal. (ES)						
Acanthococcus uvaeursi (Linnaeus, 1761)	Pal. (ES, M, FE)	Nea.					
Crytococcus fagisuga Lindinger, 1937	Pal. (ES, M, IT)	Nea.					
Gossyparia spuria (Modeer, 1778)	Pal. (ES, M, IT, FE)	Nea.					
Greenisca gouxi (Balachowsky, 1954)	Pal. (ES, M)						
Pseudochermes fraxini (Kaltenbach, 1860)	Pal. (ES, M, IT)						
Rhizococcus agropyri Borchsenius, 1949	Pal. (ES, M, IT, FE)						
Rhizococcus insignis (Newstead, 1891)	Pal. (ES, M, IT)	Nea.					
Rhizococcus pseudinsignis (Green, 1925)	Pal. (ES, M)	Nea.					
KERMESIDAE							
Kermes quercus (Linnaeus, 1758)	Pal. (ES, M, IT)						
MARGARODIDAE							
Porphyrophora polonica (Linnaeus, 1758)	Pal. (ES)						
MATSUCOCCIDAE							
Matsucoccus pini (Green, 1925)	Pal. (ES, M)						
ORTHEZIIDAE							
Arctorthezia cataphracta (Shaw, 1794)	Pal. (ES, M, IT, FE)	Nea.					
Newsteadia floccosa (De Geer, 1778)	Pal. (ES, M)						
Orthezia urticae (Linnaeus, 1758)	Pal. (ES, M, IT, FE)			Eth.	Ori.		
Ortheziola britannica Kozár & Miller, 2000	Pal. (ES)						
Ortheziola vejdovskyi Sulc, 1895	Pal. (ES, M)						
RHIZOECIDAE							
Rhizoecus albidus Goux, 1942	Pal. (ES, M, IT)						
PSEUDOCOCCIDAE							
Atrococcus achilleae (Kiritchenko, 1936)	Pal. (ES, M, IT, FE)						
Atrococcus cracens Williams, 1962	Pal. (ES, M)						
Atrococcus paludinus (Green, 1921)	Pal. (ES, M, IT, FE)						

TABLE 1. *continued*

Species Author	Zoogeographical regions						
	Pal. (subregions)	Nea.	Neo.	Eth.	Ori.	Aus.	NZ & P
Balanococcus boratynskii Williams, 1962	Pal. (ES, M)						
Brevennia pulveraria (Newstead, 1892)	Pal. (ES)				Ori.		
Ceroputo pilosellae Sulc, 1898	Pal. (ES, M, IT, FE)				Ori.		
Coccura comari (Kunow, 1880)	Pal. (ES, M, IT, FE)						
Dysmicoccus walkeri (Newstead, 1891)	Pal. (ES, M, IT, FE)						
Fonscolombia europaea (Newstead, 1897)	Pal. (ES, M, IT, FE)						
Fonscolombia tomlini (Newstead, 1892)	Pal. (ES, M, IT)						
Heliococcus bohemicusb Sulc, 1912	Pal. (ES, M, IT, FE)						
Heliococcus radicicola Goux, 1931	Pal. (ES, M, IT)						
Miricoccopsis subterranea (Newstead, 1893)	Pal. (ES, M)						
Peliococcus balteatus (Green, 1928)	Pal. (ES)	Nea.					
Peliococcus calluneti (Lindinger, 1912)	Pal. (ES)	Nea.					
Peliococcus manifectus Bochsenius, 1949	Pal. (ES, M, IT)						
Phenacoccus aceris (Signoret, 1875)	Pal. (ES, M, IT, FE)	Nea.					
Phenacoccus hordei (Lindeman, 1886)	Pal. (ES, M, IT)						
Phenacoccus interruptus Green, 1923	Pal. (ES, M, IT, FE)						
Phenacoccus piceae (Löw, 1883)	Pal. (ES, M, FE)						
Planococcus vovae (Nasonov, 1908)	Pal. (ES, M, IT)		Neo.				
Ripersia corynephori Signoret, 1875	Pal. (ES)						
Trionymus dactylis (Green, 1925)	Pal. (ES)						
Trionymus perrisii (Signoret, 1875)	Pal. (ES, M, IT, FE)						
Trionymus phalaridis Green, 1925	Pal. (ES)						
Trionymus radicum (Newstead, 1895)	Pal. (ES, M)						
Trionymus thulensis Green, 1931	Pal. (ES, FE)						
Trionymus tomlini (Green, 1925)	Pal. (ES, M, IT, FE)						
STEINGELIIDAE							
Steingelia gorodetskia Nasonov, 1908	Pal. (ES)	Nea.					
XYLOCOCCIDAE							
Xylococcus filiferus Löw, 1882	Pal. (ES, M)						

species they are classified into four groups, Palearctic (including 1–4 subregions), Holarctic (Palearctic + Nearctic), species from 2–3 regions and Cosmopolitan (more than three regions).

The Palearctic group consists of 52 species, 56.5% of the total fauna. The families Pseudococcidae and Coccidae have a strong dominance in this group (Table 1). Lagowska (2001) has divided the group into three subgroups: Species found in three or in all four subregions. This group includes 24 species (46%). Species distributed in two subregions, with 17 species (33.0%). The dominant group, with 15 species, consists of species that occur both in the Euro-Siberian and Mediterranean subregions.

Only 11 species (21.0%) are restricted to one subregion (Euro-Sibirian). This group comprises of several species, which are distributed in a few countries. Such species are e.g. *Ortheziola britannica* Kozár & Miller 2000, *Ripersia corynephori* Signoret, 1875, *Trionymus dactylis* (Green, 1925), *T. phalaridis* Green, 1925,

TABLE 2. Number of species per genus in scale insect families occurring in Fennoscandia and Denmark.

Family	Number of genera	Number of species	Ratio of species to genera
Asterolecaniidae	2	2	1.0:1
Coccidae	9	23	2.55:1
Diaspididae	8	16	2.0:1
Eriococcidae	6	12	2.0:1
Kermesidae	1	1	1.0:1
Margarodidae	1	1	1.0:1
Matsucoccidae	1	1	1.0:1
Ortheziidae	4	5	1.25:1
Pseudococcidae	14	28	2.0:1
Rhizoecidae	1	1	1.0:1
Steingeliidae	1	1	1.0:1
Xylococcidae	1	1	1.0:1
Total	*49*	*92*	*1.88:1*

Acanthococcus timidus (Huldén, 1985) and *Physokermes inopinatus* Danzig & Kozár, 1973.

In the Holarctic group some of the species are characterized as circum-boreal. This group consists of 17 species, 18.5% of the total fauna. Half of the species belong to the family Eriococcidae. The group includes such well known pests as *Phenacoccus aceris* (Signoret, 1875), *Cryptococcus fagisuga* Lindiger, 1937, *Physokermes hemicryphus* (Dalman, 1826), *P. piceae* (Schrank, 1801) and *Pulvinaria vitis* (Linnaeus, 1758). A typical circumpolar, boreo-alpine species, in Sweden, Norway and Finland is *Arctorthezia cataphracta* (Shaw, 1794). The third group, 10 species, and 10.9% of the total fauna, consists of species which have been recorded from 2–3 zoogeograhical regions. These species are found in Palearctic as well as in Nearctic, Neotropical or Oriental regions, e.g. *Chionaspis salicis* (Linnaeus, 1758), which occurs in Palearctic, Nearctic and Orienal regions. This species is the most abundant species in Fennoscandia and Denmark. The Cosmopolitan species consists of 13 species, 14.1% of the total fauna. Whilst these species seldom cause any damage in Fennoscandia and Denmark, elsewhere they are mostly known as polyphagous pest species. Most of the species belong to the family Diaspididae.

The ratios and the number of species per genus are shown in Table 3. This ratio, 1.88:1, is very close to the German (1.85:1) and Polish fauna (1.99:1) (Lagowska & Golan 2011 pers. comm.). In Russia the calculated ratio is 2.95:1 (Ben-Dov *et al*. 2012). The analysis shows that the largest number of shared species was found between Fennoscandia and Denmark and Germany and Poland respectively (Figure 2). This is also the result from the Sørensen index calculations (Table 4). The highest index is between Fennoscandia and Denmark and Poland together with Germany and Poland and the lowest between Germany and Russia.

Discussion

The method in this study where the ratio of species to genera was calculated is used by several scale insect researchers (Ben-Dov 1990, Kozár & Ben-Dov 1997, Lagowska 2001) and has long been used as a tool in biogeography as a reflection on the global history of diversification and range expansion. As previously noted, the ratios depend on the area studied and also significantly on the numbers of species (Järvinen 1982). The ratios are lower in insular or local biotas than in corresponding mainland (source) areas or the

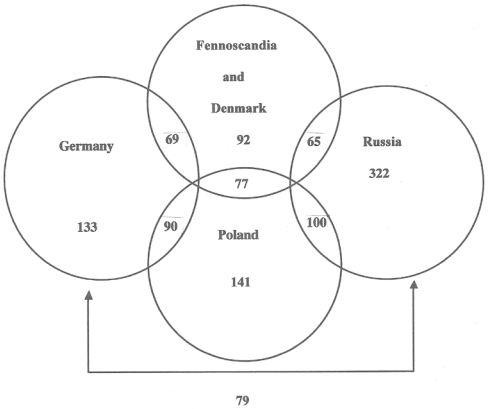

FIGURE 2. Venn diagram of the number of and shared species in Fennoscandia and Denmark and adjacent countries.

TABLE 3. Comparisons of the average number of Coccoidea species per genus in some countries and regions.

Region/country	Number of genera	Number of species	Ratio of species to genera	Reference
Fennoscandia and Denmark	49	92	1.88:1	Gertsson, present study
Germany	72	133	1.85:1	ScaleNet (2012)
Poland	71	141	1.99:1	Lagowska & Golan (pers. comm. 2011)
Russia	109	322	2.95:1	ScaleNet (2012)
Palaeartic Euro-Siberian	93	257	2.76:1	Kozár (1995)
Palearctic	372	2170	5.83:1	Kozár (1998)

TABLE 4. Sørensen index for comparing the similarity of species between Fennoscandia and Denmark and adjacent countries.

Countries	Sørensen index
Fennoscandia/Denmark – Germany	0.61
Fennoscandia/Denmark – Poland	0.66
Fennoscandia/Denmark – Russia	0.31
Germany – Poland	0.66
Poland – Russia	0.43
Germany – Russia	0.35

entire species pool. The species-to-genus ratios increase by the number of species (Järvinen 1982). This is obvious when we compare the ratios between Fennoscandia and Denmark and Russia and Palearctic (Table 3).

Still, it is interesting to compare results presented here with a similar investigation from Poland (Lagowska 2001). In spite of the small coccids fauna in Fennoscandia and Denmark we can see high similarities between the fauna of Poland and Fennoscandia and Denmark. The most remarkable of which is that the families Pseudococcidae and Coccidae have the largest species number. The same phenomenon was noted in a study of the fauna of the Euro-Siberian subregion of the Palearctic region (Kozár & Drozdják 1986). The family Pseudococcidae is the second largest family, with over 2000 species in the world fauna. In addition this family has the largest number of species (708) in the Palearctic region followed by the Nearctic region (428). The family Coccidae is the third richest with over 1000 world-wide (Ben-Dov *et al*. 2012). The highest number of species are in the Neotropical, Palearctic and Ethiopian regions, suggesting a high rate of speciation in these areas, especially on widely distributed woody plants (Kozár & Ben-Dov 1997). The ratios of species to genera are highest in the families Eriococcidae and Coccidae in Fennoscandia and Denmark as well as in Poland. The family Eriococcidae is the fourth richest with over 600 species and what is presumed to be one of the oldest families of Coccoidea (Kozár 2009). The number of species is the largest in Palearctic (198) (Kozár 2009, Ben-Dov *et al*. 2012). 50% of the species in the Holarctic group belong to the family Eriococcidae. Four of the species in the Holarctic group belong to the genera *Acanthococcus* and *Rhizococcus*, which are characterised by a large number of species in the Palaearctc region. *Acanthococcus* has a high number of species in the Nearctic region (Kozár 2009). The group, whose range is limited to 2–3 zoogeographical regions, has as the Cosmopolitan group a widely distributed fauna. Half of the number of species is the same as in the Polish study. Many of the species in the Cosmopolitan group have a well known extraeuropean origin. They exibit the most diversified types of distribution and were introduced into Fennoscandia and Denmark with cultivated and ornamental plants e.g. *Parthenolecanium persicae* (Fabricius, 1776), *Pulvinaria floccifera* (Westwood, 1870), *Aulacaspis rosae* (Bouché, 1833), *Carulaspis minima* (Signoret, 1869), *Diaspidiotus ostreae-formis* (Curtis, 1843) and *D. perniciosus* (Com-stock, 1881). Many of the species belong to the family Diaspididae. This family is the most studied of Coccoidea (Kozár 1990). The Diaspididae is the largest family

within the Coccoidea, containing approximately 400 genera and 2500 species (Ben-Dov *et al*. 2012). Many are serious pests e.g. *Diaspidiotus perniciosus* (Comstock, 1881). This species was recorded only once in Denmark in 1964 (Kozarzhevskaya & Reitzel 1975). According to Kozár (1995a) the northern limit of this species distribution is 48–50° of northern latitude.

The presented distributional pattern in this analysis will change with subsequent records, as many new species will inevitably be introduced to Fennoscandia and Denmark due to increasing foreign trade and climatic changes. Scale insects are one of the most successful invaders of new geographical areas (Pellizzari & Dalla Montá 1997). We have recently got two invasive and harmful species in Sweden and one in Denmark. In 2006 *Pulvinaria regalis* Canard, 1968 (Horse Chestnut Scale), was found for the first time in south Sweden (Gertsson 2011a). Since this discovery, a significant northward expansion of the species has been recorded in the Swedish province (Scania) (Gertsson 2011b). In addition it is well distributed and abundant in the city of Copenhagen (Gertsson 2007). During the summer of 2010, *Physokermes inopinatus* Danzig & Kozár 1973 (Hungarian Spruce Scale), was also found in the south of Sweden (Scania), where it had an outbreak that killed Norway spruce trees (*Picea abies*). Several areas, in all approximately 1000 ha, were severely damaged. Whether *P. inopinatus* has been introduced to Sweden or whether it has occurred in the country for a longer time is not clear (Gertsson & Isacsson 2012b). This nortward shift of the two species could be the result of climate change (Kozár 1997) or foreign transport around Europe. Hopefully this work represents a starting point for further zoogeographical studies in our region.

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