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Assessment of the potential impact of American *Spodoptera* species for the European Union

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Summary

Reason for performing the assessment
Spodoptera species (armyworms) belong to the Noctuidae. The larvae cause damage by consuming plant parts. Currently, four *Spodoptera* species are regulated in the European Union, *S. eridania, S. frugiperda, S. litura* and *S. littoralis* of which the first two species are present in the Americas. However, many more *Spodoptera* species which may be a threat to plant health in the EU. The reason for performing he present study is the interceptions of several non-regulated *Spodoptera* species in the Netherlands on plants and plant products originating in the Americas. The study assesses the potential impact of the different *Spodoptera* species that are present in the Americas. For those species that are considered of economic importance for the EU, a full Pest Risk Analysis, including a pathway-analysis, a more detailed assessment of the endangered area and an evaluation of risk reduction options could be conducted at a later stage.

PRA area
European Union (EU).

Spodoptera species included
Eighteen *Spodoptera* species were identified to be present on the American continents of which 12 species were selected for further assessment (Table S1). For the six species that were not selected (*S. compta, S. descoinsi, S. evanida, S. hipparis, S. marima* and *S. roseae*) very little information was available and they seemed not to be of economic importance. *S. exigua,* that originates in Southeast Asia and is currently present on nearly all continents including North America and Europe, was included for comparison.

Table S1. The distribution of twelve *Spodoptera* species in South America and North America, that were included in the present risk assessment.

Spodoptera sp.	Species present?			
	South America	North America		
		Central America and Mexico	Caribbean and Bermuda	Canada, USA[1]
S. albula	yes	yes	yes	yes
S. androgea	yes	yes	yes	yes[3]
S. cosmioides	yes	yes	yes[4]	no records found
S. dolichos	yes	yes	yes	yes
S. eridania (EU-IAI)[2]	yes	yes	yes	yes
S. exigua (non-native)	Uncertain	yes	yes	yes
S. frugiperda (EU-IAI)	yes	yes	yes	yes
S. latifascia	no	yes	yes	yes
S. ochrea	yes	no records found	no records found	no records found
S. ornithogalli	yes	yes	yes	yes
S. praefica	no records found	no records found	no records found	yes
S. pulchella	no records found	no records found	yes	yes[3]

[1] United States of America

[2] EU-IAI: organism listed in Annex IAI of Directive 2000/29/EC (organism not known to occur in the EU and regulated for all plants and products).

[3] Florida only

[4] Trinidad and Tobago only

Host plants
The *Spodoptera* species listed above are polyphagous. Each species attacks plant species from different plant families. Host plants include various economically important crops like tomato, *Brassica*, *Capsicum*, onion and maize. Some host preference occurs. *Spodoptera frugiperda* is known to prefer Poaceae (e.g. maize, sorghum rice and sugar cane) but can also cause serious injury to various dicot crops. The other species can also feed on a wide range of plant species but are (generally) less important as a pest on Poaceae than *S. frugiperda.*

Area of potential establishment
It is assessed that most of the twelve *Spodoptera* species listed above (Table S1) can overwinter in at least the southernmost parts of the EU (*S. exigua* is already present in the EU) and several may migrate to more northern areas during summer. The exact northern border where the species can overwinter is difficult to predict because of the lack of information on the current distribution of overwintering populations and climatic requirements for the species to establish.

Potential consequences
Four out of the 11 American *Spodoptera* species listed above, were assessed to be of significant economic importance for the EU: *S. eridania*, *S. frugiperda*, *S. ornithogalli* and *S. praefica,* of which *S. eridania* and *S. frugiperda* are currently regulated in the EU. The other 7 species, are either not known to cause significant impacts in their current area of distribution or are only known as pests in tropical areas (*S. albula, S. androgea, S. cosmioides, S. dolichos, S. latifascia, S. ochrea* and *S. pulchella*). Therefore, their potential impact is assessed to be minor for outdoor crops in the EU. They are neither expected to become significant greenhouse pests in commercial crops because they are not known as such in their current area of distribution. In tropical non-commercial greenhouses (e.g. zoos and botanical gardens), they might be able to establish and cause significant impacts.

Endangered area for *S. eridania*, *S. frugiperda*, *S. ornithogalli* and *S. praefica*

S. eridania and *S. frugiperda*
S. eridania and *S. frugiperda* are considered pests of economic importance mainly in the southeastern parts of the USA. Therefore, both species seem especially a threat to crop production in southern EU member states. Both species can damage many crops. Economically important crops that are expected to be seriously damaged include tomato for *S. eridania* and maize and other Poaceae for *S. frugiperda*. Incidental or locally significant damage may occur in more northern EU member states through migratory populations during summer.

S. ornithogalli
In North-America *S. ornithogalli* is assumed to overwinter in more northern areas than *S. eridania* and *S. frugiperda.* However, it is considered a pest of economic importance mainly in the southeastern parts of the USA. Occasionally, significant damage occurs in more northern parts of the USA. Hence, the endangered area of S*. ornithogalli* may not be much different from that of *S. eridania* and *S. frugiperda*. The species is known as a pest of tomato and several other crops.

S. praefica
Like S. ornithogalli, S. praefica is assumed to overwinter in more northern areas than *S. eridania* and *S. frugiperda.* Currently, the pest is only known from the western USA and western Canada where it is known as an occasional pest of various crops including tomato and forage crops. Impacts may occur in northwestern USA but the pest is especially of importance in agricultural areas in California. Therefore, the southern part of the EU is assessed to be the primary endangered area for this species.

Greenhouses
In areas with outdoor populations of *S. eridania*, *S. frugiperda*, *S. ornithogalli* and *S. praefica,* these pests may regularly enter greenhouses and cause crop damage. In northern areas further away from their overwintering sites, the species are not expected to become important greenhouse

pests based on the fact that they are not known as such in North America. In this respect they seem to differ from *Spodoptera exigua* that is known as greenhouse pest both in North America and Europe.

Economic impact – rating level

The potential impact of the species is assessed to be generally "medium" meaning that targeted measures are necessary to keep yield and and/or quality losses low and crop protection costs are average. Locally or occasionally, "major" impacts may occur ("major impact": frequent or expensive measures are needed to keep losses limited; significant increase in crop protection costs). Impacts may, however, increase if (biological) pesticides to control Lepidopteran pests would no longer be effective.

Environmental impact – rating level

In the current area of distribution, the *Spodoptera* species seem mainly or only a problem in agricultural areas and it is assessed that the environmental impact will be "minimal" or "minor" for the EU.

Main uncertainties

Because exact data were missing on overwintering sites and population biology, detailed assessments of the potential areas of distribution for each *Spodoptera* species was not possible. Quantitative data on yield losses are also lacking for most species. Hence the uncertainty of the assessment of the potential impact for the EU is medium.

Early instars of many of the *Spodoptera* species are hard to distinguish from each other. Damage may have been attributed to the wrong *Spodoptera* species, for example to a species that was already known as a pest in the area or in the crop. In addition, damage is often reported as being caused by a *Spodoptera*-complex, consisting of more than one *Spodoptera* species. The true extent of the damage caused by the different *Spodoptera* species is therefore not always clear.

The host range of the *Spodoptera* species may be wider than the list of plant species on which they have been reported. For example, feeding damage on plants species that are commercially not very important may not have been reported.

Table of contents

1. Introduction

Several *Spodoptera* species (armyworms) are known as serious plant pests worldwide and four *Spodoptera* species are regulated in the European Union (EU, 2017):

- *S. littoralis* (IAII)
- *S. litura* (IAI)
- *S. eridania* (IAI)
- *S. frugiperda* (IAI)

The NPPO (National Plant Protection Organisation) of the Netherlands regularly intercepts these *Spodoptera* species on produce and sometimes also on plants for planting[1]. However, other non-quarantine *Spodoptera* species have been intercepted over the years especially from American countries. For these species, the NPPO has made short initial risk assessments (Quickscans) to determine if statutory action is needed (https://english.nvwa.nl/topics/pest-risk-analysis/contents/quick-scans) and for two species, *S. dolichos* and *S. cosmioides*, emergency measures are taken if the species is found on plants for planting. In the present study, a more extensive assessment has been made of the potential impact of these and other American *Spodoptera* species for the European Union. For those species that are considered of significant economic importance, conducting a full Pest Risk Analysis including a pathway-analysis and an evaluation of risk reduction options should be considered in a next phase.

The main goal of the present study was to assess which American *Spodoptera* species can significantly affect plant health in the EU if they were to become established. The current impact of *S. exigua* in America and Europe was assessed for comparison. *S. exigua* is a species that originated in Southeast Asia but is now present on various continents including North America and Europe.

[1] Plants for planting: Plants intended to remain planted, to be planted or replanted (FAO, 2017)

2. Identification of Spodoptera species

2.1 The genus Spodoptera

Taxonomic position: Insecta
Lepidoptera
Noctuidae
Noctuinae (Regier et al. (2016)
Name: Spodoptera Guenée, 1852
Synonyms: *Laphygma, Prodenia*
Common name: Army worms

2.2. Spodoptera species present in America

Eighteen *Spodoptera* species that are present in South, Central and North America were identified (Pogue, 2002; Pogue, 2011; Table 2.1). Note that the African species *S. exempta* was not included. This species has established in Hawaii (Pogue, 2002) but is not known to be present on the North or South American continents. *S. exigua* is native to Asia but has been introduced into many other parts of the world including North America and Europe. It was included in the present study for comparison.

The taxonomy of species within the genus *Spodoptera* has been frequently changed in the past and the status of several species is still being discussed amongst taxonomists today. Some species have been described or re-instated as valid species only recently. For example, *S. descoinsi* has been separated from *S. latifascia* only in 1994 (Lalanne-Cassou & Silvain, 1994), and *S. cosmioides* was re-instated as valid species only in 1997 (Silvain & Lalanne-Cassou, 1997). A recent study (Dumas et al., 2015), however, highlights the ambiguity of the status of *S. cosmioides* and *S. descoinsi* again. The same study also supports the synonymy of *S. marima* with *S. ornithogalli* and furthermore suggests the existence of potential new species clusters for *S. exigua* and *S. frugiperda*. The results of that study however are not (yet) supported by other taxonomists. In the present risk assessment we consider the species listed in Pogue (2002) and Pogue (2011) as valid (Table 2.1).

Little information is available about some of the 18 species known from the Americas For example, *S. compta* and *S. roseae* are extremely rare in collections with *S. compta* only known from three specimens collected in the 19th century (Dumas et al., 2015). *Spodoptera* species for which little information was available and which had not been reported as pests are not discussed further in the present study. They are not considered plant pests of significant economic importance. These species were: *S. compta, S. descoinsi, S. evanida, S. hipparis, S. marima* and *S. roseae.*

Table 2.1 *Spodoptera* species known to be present in America (South, Central and North America and the Caribbean)

Preferred name[1]	Synonyms[2]	Common names[3]	EPPO Code	EU status?[4]
***Spodoptera albula* (Walker, 1857b)**	*Spodoptera sunia, Prodenia sunia Xylomyges sunia*	white-spotted armyworm, unbarred armyworm, grey-streaked armyworm, Costa Rican armyworm	PRODSU	No
***Spodoptera androgea* (Stoll *in* Cramer, 1782)**		androgea armyworm	-	No
Spodoptera compta (Walker, 1869)		-	-	No
***Spodoptera cosmioides* (Walker, 1858)**	*Spodoptera cosmiodes* (Note: is mispelling)	-	SPODCO	No
Spodoptera descoinsi (Lalanne-Cassou & Silvain, 1994)	-	-	-	No
***Spodoptera dolichos* (Fabricius, 1794)**		sweet potato armyworm, large cotton armyworm, dolichos armyworm	SPODDO	No
***Spodoptera eridania* (Stoll *in* Cramer, 1782)**	*Prodenia eridania*	southern armyworm, semitropical armyworm	PRODER	IAI
Spodoptera evanida Schaus, 1914	-	-	-	No
***Spodoptera exigua* (Hübner, 1808)**	*Laphygma exigua*	beet armyworm, lesser armyworm	LAPHEG	No
***Spodoptera frugiperda* (Smith, 1797)**	*Laphygma frugiperda*	fall armyworm	LAPHFR	IAI
Spodoptera hipparis (Druce, 1889)	*Leucochlaena hipparis*	-	SPODHI	No
***Spodoptera latifascia* (Walker, 1856)**	*Prodenia latifascia*	orange-striped armyworm, lateral lined armyworm, garden armyworm, velvet armyworm		
Spodoptera marima (Schaus, 1904)		-	-	No
***Spodoptera ochrea* (Hampson, 1909)**	*Xylomyges ochrea, Prodenia ochrea*	-	SPODOC	No
***Spodoptera ornithogalli* (Guenée, 1852)**	*Prodenia ornithogalli*	yellow-striped armyworm	PRODOR	No
***Spodoptera praefica* (Grote, 1875)**	*Prodenia praefica*	western yellow-striped armyworm	PRODPR	No
***Spodoptera pulchella* (Herrich-Schäffer, 1868)**		Caribbean armyworm	-	No

Preferred name[1]	Synonyms[2]	Common names[3]	EPPO Code	EU status?[4]
Spodoptera roseae (Schauss, 1923b)	-	-	-	No

[1] Twelve species (indicated in bold) were selected for further assessment.
[2] Synonyms: only names are included that have been found in scientific literature published since about 1950.
[3] Common English names: only names commonly used on websites and in applied and extension services documents, and that are not ambiguously used for more than one species
[4] Listed in Annex I or II of Council Directive 2000/29/EC (EU, 2017)

3. Host range

3.1 Methodology for literature search

In the present study, we focused on host plant records that were relevant for the assessment of the potential impact of the different *Spodoptera* species for the EU. The aim was not to make a full list of all known host plants for each species. For *S. exigua*, *S. eridania* and *S. frugiperda* data were mainly derived from review papers of Pogue (2002) and Wagner et al. (2012) and the database HOSTS and the Crop Protection Compendium (Robinson et al., 2010; CABI, 2016). These species are well known pests and review papers and databases provided the information needed. For the other *Spodoptera* species (not regulated and not known to be present in Europe), a more extended search was done using CAB-abstracts (search term 'name of species'), internet (Google) and through contacts in the field. We focused on records of the species on crops that are of importance to the EU but records of other host plants were also listed when found (e.g. tropical plant species that are not grown or only to limited extend in the European Union). In Chapter 6 (Economic impact), we tried to find primary records of feeding, and more specifically damage on crops and other plants.

3.2. Results

Each *Spodoptera* species discussed in the present PRA is polyphagous and attacks plant species of more than one plant family (Table 3.1). Some *Spodoptera* species (*S. androgea* and *S. pulchella*) seem to have a less wide host range than others, but that may also be due to the fact that those species are rarer and of less economic importance and consequently far less information has been published about these species.

Several *Spodoptera* species feed on plant species that are of importance for the EU, for example tomato, maize, *Capsicum* and onion. *S. frugiperda* is known to prefer Poaceae (e.g. maize, sorghum rice and sugar cane) but can also cause serious injury to various dicot crops (Capinera, 2014c; EPPO, 1997; Pitre & Hogg, 1983). The other species can also feed on a wide range of plant species but are (generally) less important as a pest on Poaceae than *S. frugiperda.* It should be noted that differences in host plant preference may exist between populations within the same species because host plant preference in polyphagous insects can be influenced by the plant species on which the larvae first feed and on which the adults mate (EPPO, 1997; Proffit *et al.* 2015).

Table 3.1. Host plants of 12 *Spodoptera* species that are present in America.

***Spodoptera* species**	**Host plants**	**References**
S. albula	Very wide host range, amongst others *Agave sisalana, Allium, Amaranthus, Arachis hypogaea , Asparagus officinalis, Beta vulgaris var. saccharifera, Boerhavia, Brassica, Brassica oleracea var. capitata, Brassicaceae, Capsicum, Capsicum annuum, Chrysanthemum, Chrysanthemum indicum, Cucurbitaceae, Cynara scolymus, Daucus carota, Fragaria, Glycine max, Gossypium, Helianthus, Impatiens, Ipomoea batatas, Linum usitatissimum, Manihot esculenta, Musa, Nicotiana, Nicotiana tabacum, Phaseolus vulgaris, Pisum, Pisum sativum, Plerandra (syn. Dizygotheca), Portulaca oleracea, Sesamum indicum, Solanum lycopersicon (syn. Lycopersicon esculentum), Solanum tuberosum, Sorghum bicolor, Tobacco, Zea mays, Zephyranthes.*	CABI, 2016; Maes & Tellez Robleto, 1988; Montezano et al., 2013; Robinson et al., 2010; Pogue & Passoa, 2000; Teixeira et al., 2001, NVWA-interceptions, Meagher (pers. comm.)
S. androgea	*Amaranthus, Ananas comosus, Apium graveolens, Cocoa, Lactuca, Lycopersicon, Musa sp., Piper sp., Theobroma cacao, Xanthosoma, Zea mays.*	Dinther, 1960; Pogue, 2002; Wagner et al., 2012; Zagatti et al., 2006; Zucchi & Silveira Neto, 1984; NVWA-interceptions
S. cosmioides	Very wide host range: 126 plant species belonging to 40 families are listed as hosts of *S. cosmioides*, including Asteraceae, Fabaceae, Poaceae and Solanaceae.	Bavaresco et al. 2003; Boica jr. et al., 2013; Cabezas et al, 2013; Oliviera et al., 2014, Pogue & Passoa, 2000; Rolim et al., 2013; Rodrigues de Araújo, 2009; Silva et al., 2011; Solano et al., 2015; Specht et al., 2016; NVWA-interceptions
S. dolichos	Very wide host range, amongst others: *Acaena eupatoria, Allium cepa, Amaranthus spinosus, Apium graveolens, Arachis hypogaea, Asparagus officinalis, Axonopus compressus, Brassica oleracea, Brassica rapa, Brugmansia, Carya, Capsicum, Celosia cristata, Cestrum, Citrullus vulgaris, Coffea, Commelina communis, Coronopus didymus, Crotalaria breviflora, Crotalaria spectabilis, Datura stramonium, Dianthus plumarius, Eruca sativa, Fevillea cordifolia, Fragaria, Glycine max, Gossypium, Gossypium barbadense, Gossypium herbaceum, Ipomoea batatas, Lolium multiflorum, Lupinus rivularis, Lycopersicon, Momordica (charantia), Nephthytis sp, Nicandra physalodes, Nicotiana, Nicotiana tabacum, Pennisetum purpureum, Petunia*	Maes & Tellez Robleto, 1988; Montezano et al., 2016; Pogue & Passoa, 2000; Robinson et al., 2010; Teixeira & Yokomizo, 1987; Solano et al.,

***Spodoptera* species**	**Host plants**	**References**
	integrifolia, Phaseolus vulgaris, Philodendron cordatum, Physalis, Pisum sativum, Poa annua, Polygonium punctatum, Portulaca oleracea, Ricinus communis, Rubus idaeus, Saccharum officinarum, Senecio bonariensis, Solanum, Solanum lycopersicon (syn. Lycopersicon esculentum), Solanum macrocarpon, Solanum melongena, Solanum rugosum, Solanum tuberosum, Theobroma cacao, Tradescantia virginiana, Trifolium, Vernonia nudiflora, Vernonia tweedieana, Viola, Viola tricolor, Zea mays, Zingiber officinale.	2015; NVWA-interceptions
S. eridania	Very wide host range. At least 106 host plant species from 31 families; most important host plant families are Amaranthaceae, Asteraceae, Brassicaceae, Convolvulaceae, Cucurbitaceae, Cyperaceae, Euphorbiaceae, Fabaceae, Lamiaceae, Malvaceae, Phytolaccaceae, Poaceae, Polygonaceae, Rosaceae, Rubiaceae and Solanaceae .	FAO, 2016
S. exigua	Very wide host range	CABI, 2016
S. frugiperda	Very wide host rage with 186 host plants from 42 families. Most important host plant family is Poaceae, but it feeds on many more plant families including Amaranthaceae, Asteraceae, Brassicaceae, Cyperaceae, Fabaceae, Rosaceae and Solanaceae.	FAO, 2016
S. latifascia	Very wide host range, amongst others: *Allium cepa, Amaranthus sp., Arachis hypogaea, Areca, Asparagus officinalis, Avena sativa, Beta cicla, Capsicum annuum, Citrus, Citrus maxima, Eucalyptus, Eulophia alba (Orchidaceae), Glycine max, Gossypium, Gossypium barbadense, Gossypium herbaceum, Gossypium hirsutum, Helianthus annuus, Ipomoea sp., Ixophorus unisetus, , Luffa fricatoria, Lycopersicon, Melampodium divaricatum, Medicago sativa, Nicotiana, Nicotiana tabacum, Parthenium hysterophorus, Phaseolus vulgaris, Pilea, Portulaca oleracea, Plumbago auriculata, Schefflera, Sorghum bicolor, Solanum lycopersicon (*syn. *Lycopersicon esculentum), Solanum tuberosum, Zea mays*	Ingram, 1978; Maes & Tellez Robleto 1988, Morales Valles et al., 2003; Pogue, 2002; Portillo, 1996; Remillet, 1988; Robinson et al., 2010; NVWA-interceptions
S. ochrea	Very wide host range: *Amaranthus dubius, Asparagus officinalis, Brassica oleracea, Capsicum annuum, Cucumis sativus, Cucurbita spp, Cynara scolymus, Gossypium hirsutum, Lycopersicon pimpinellifolium, Medicago sativa, Nicotiana tabacum, Phaseolus vulgaris, Solanum lycopersicon, Solanum tuberosum, Tagetes erecta, Zea mais*. Also in other crops and weeds in amongst others the families Amaranthaceae, Aliaceae, Brassicaceae, Liliaceae, Solanaceae,).	Diaz-Silva, 2017; Estupinan & Ortiz, 1983; Luna Rodriguez et al., 2002; Pogue & Passoa, 2000; Sánchez & Vergara, 2003; NVWA-interceptions
S. ornithogalli	Very wide host range, amongst others: *Allium cepa, Allium cernuum, Amaranthus retroflexus, Amaranthus spinosus, Arachis hypogaea, Asparagus officinalis, Aster, Baccharis halimifolia, Baccharis neglecta, Beta vulgaris, Brassica napus, Brassica oleracea, Brassica rapa, Capsicum frutescens, Carica papaya, Cercis canadensis, Chenopodium album, Citrullus lanatus, Citrus sinensis, Conyza canadensis, Cornus sp., Cosmos bipinnatus, Cucumis sativus, Cucumis melo, Dahlia pinnata, Datura stramonium, Daucus carota, Erigeron canadensis, Gladiolus, Glycine max, Gossypium, Gossypium herbaceum, Gossypium hirsutum, Grindelia, Helianthus annuus, Hibiscus, Ipomoea alba, Ipomoea batatas, Ipomoea purpurea, Lactuca sativa, Lactuca scariola, Lens culinaris, Luffa fricatoria, Lycopersicon, Medicago sativa, Melilotus, Momordica, Musa paradisiaca, Nicandra physalodes, Nicotiana, Nicotiana tabacum, Petunia axillaris, Phaseolus, Phaseolus lunatus, Phaseolus vulgaris, Phytolacca americana, Pisum sativum, Plantago lanceolata, Platanus occidentalis,*	Capinera, 2014a; Edelson & Hyche, 1980; Pogue & Passoa, 2000; Robinson et al., 2010; NVWA-interceptions

***Spodoptera* species**	**Host plants**	**References**
	Populus deltoides, Prunus persica, Quercus acutissima, Quercus prinus, Rheum rhaponticum, Rheum rhabarbarum, Ricinus communis, Robinia pseudoacacia, Rosa, Rubus allegheniensis, Rubus idaeus, Rumex, Sida spinosa, Solanum, Solanum carolinense, Solanum lycopersicon (syn. Lycopersicon esculentum), Solanum melongena, Solanum tuberosum, Solidago leavenworthii, Sorghum bicolor, Tradescantia hirsutiflora, Tragopogon, Tragopogon porrifolius, Trifolium, Triticum aestivum, Vernonia noveboracensis, Vigna unguiculata, Viola, Vitis vinifera, Xanthosoma violaceum, Zea mays	
S. praefica	Very wide host range, amongst others: *Allium cepa, Asparagus officinalis, Beta vulgaris, Centaurea solstitialis, Chenopodium album, Crataegus, Cucumis melo, Daucus carota, Erodium, Erodium cicutarium, Gossypium, Gossypium herbaceum, Grindelia camporum, Helianthus, Ipomoea purpurea, Lactuca serriola, Lens culinaris, Lupinus albus, Lycopersicon, Malus pumila, Medicago sativa, Melilotus officinalis, Oryza sativa, Phaseolus, Phaseolus vulgaris, Pisum sativum, Polygonum, Prunus persica, Pyrus communis, Rubus allegheniensis, Rubus idaeus, Rubus parviflorus, Rubus vitifolius, Salsola kali, Setaria, Sinapis arvensis, Smilax californica, Solanum lycopersicon (syn. Lycopersicon esculentum), Solanum tuberosum, Sonchus oleraceus, Sorghum bicolor, Trifolium cyathiferum, Vigna unguiculata, Vitis, Vitis vinifera*	Babcock et al., 1993; Benedict & Cothran, 1980; Grigarick, 1984; Halfhill, 1982; Nandwani, 2013; Robinson et al., 2010; Pogue, 2002; Summers, 1989; Tagahashi, 2002; Wagner et al., 2012.
S. pulchella	*Gossypium, Gossypium barbadense, Orchids, Taraxacum*	Anonymous, 2012; Pogue, 2002; Robinson et al., 2010; Wagner et al., 2012.

4. Current area of distribution

Ten of the 12 species identified and selected in Chapter 2 (including *S. exigua* originating from outside the Americas) are present in the USA (Table 4.1; Fig. 4.1). Some have been recorded in several US states up to the border of Canada or even in southern Canada (Fig. 4.1). Most of the species most likely survive the winter season in the very southern states only and (most) findings in more northern areas are likely due to summer migration from southern states although the exact overwintering sites are not known (e.g. Capinera, 2014bd; Heppner, 1998; Sparks, 1986; Westbrook et al., 2016). "None are known to survive prolonged periods of freezing" (Wagner et al., 2012). Exact conditions under which pupae or other life stages can survive the winter season are often not known. Overwintering sites may vary from year to year depending on winter temperatures. In general, data are lacking to assess precisely the areas where the different *Spodoptera* species are present throughout the year and those areas where the species is only a summer migrant. Species differ, however, in tolerance to cold weather. *S. frugiperda* has, for example, no diapause in any stage (including the pupae) and is usually killed at temperatures below zero (Capinera, 2014b; EPPO, 1997). Survival percentages appear to be higher in areas with warmer winters. Wood et al. (1979) found survival percentages of the pupal stage of 51.0%, 27.5% and 11.6% survival in southern, central and northern Florida, respectively. *Spodoptera ornithogalli* and *S. praefica* overwinter outdoors in more northern areas than most of the other *Spodoptera* species that are present in North America and overwintering sites of these species are, therefore, discussed in more detail below. Below we discuss to what extent *Spodoptera* species are known as greenhouse pests.

Spodoptera ornithogalli
In 2012, tomato fruit damage by *S. ornithogalli* was observed in Pennsylvania (plant hardiness zones 5-7; http://planthardiness.ars.usda.gov/, accessed 23 February 2017). Fleischer (2012) suggested that the species had overwintered more to the north and thus closer to Pennsylvania than in other years because of the very mild preceding winter. Fleischer (2012) also stated the following: "pupae of this species can withstand colder temperatures and the species overwinters in North Carolina and Kentucky but rates of overwintering probably increase in more southern areas". North Carolina and Kentucky have plant hardiness zones of 7 to 8 and 6 to 7, respectively. The assessment that *S. ornithogalli* survives in more northern areas than most other *Spodoptera* species is supported by observations in the northeastern United States where *S. ornithogalli* is the first to arrive, often in the spring. *Spodoptera frugiperda* usually arrives in appreciable numbers only after mid-August, and other species, if arriving at all in the Northeast, only from September to November (Wagner et al., 2012).

Spodoptera praefica
The distribution of *S. praefica* is limited to the western states of the USA and southwestern Canada (Table 4.1; Fig. 4.1). The species is migratory and spread northwards from the southwest each year (Entomology Collection, 2013; PNW Moths, 2017). However, its overwintering sites are not clear. For California, records of the species are available from January to September but not from October to December. From other states records are available from (May) June to August (September) which suggest that they do not overwinter in these states. For Washington it is less clear because records are available from March to September (http://mothphotographersgroup.msstate.edu/large_map.php?hodges=9667; 23 February 2017). Washington (north western USA) has plant hardiness zones that vary from 4 to 9 (8 to 9 in the western part; http://planthardiness.ars.usda.gov/PHZMWeb/, 23 February 2017). It is uncertain what the minimum requirements are for winter survival but the species may be able to overwinter in the western part of Washington.

Spodoptera in greenhouses
Information on *Spodoptera* as greenhouse pests is scarce. Several species that are present outdoors in Florida may also be found in greenhouses in Florida (pers. comm. R.L. Meagher, USDA-ARS, Florida). However, the species do not appear to be particular greenhouse pests with the exception of *S. exigua*. Capinera (2014d) states about *S. exigua*: "except in greenhouses, it rarely is a pest except in southern states". In Europe, *S. exigua* is also known as a greenhouse pest.

Table 4.1. Distribution of 12 *Spodoptera* spp. in America.[*1]

Spodoptera sp.	South America	North America			References[1]
		Central America and Mexico	Caribbean and Bermuda	Canada, USA	
S. albula	Argentina, Brazil, Colombia, Ecuador, French Guiana, Guyana, Paraguay, Peru, Venezuela	Belize, Costa Rica, El Salvador, Guatamala, Honduras, Mexico, Nicaragua, Panama	Antigua, Bahamas, Barbados, British Virgin Islands, Cayman Islands, Cuba, Dominica, Dominican Republic, Grenada, Haiti, Jamaica, Puerto Rico, St Croix, St. Kitts and Nevis, St. Vincent, Trinidad and Tobago	USA	Passoa, 1991; Pogue, 2002; Young et al., 2013
S. androgea	Brazil, Ecuador, French Guiana, Peru, Suriname, Venezuela	Costa Rica, El Salvador, Guatamala, Honduras	Cuba, Dominican Republic, Grenada, Haiti, Jamaica, Puerto Rico, St. Lucia, St. Vincent and the Grenadines	USA[2]	Passoa, 1991; Patterson, 2014; Pogue, 2002; Remillet, 1988; Young et al., 2013; NVWA-interceptions on produce from Suriname
S. cosmioides	Argentina, Bolivia, Brazil, Colombia, Ecuador, French Guiana, Guyana, Paraguay, Peru, Suriname, Venezuela	Costa Rica, Panama	Trinidad and Tobago	No records found	Young et al., 2013; NVWA-interceptions on produce from Costa Rica and Suriname
S. dolichos	Brazil, Colombia, Suriname	Costa Rica, Guatamala, Honduras, Mexico, Nicaragua, Panama	Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, St. Lucia, Trinidad and Tobago	USA	Passoa, 1991; Pogue, 2002; Remillet, 1988; Young et al., 2013; NVWA-interceptions on produce from Suriname
S. eridania	Argentina, Brazil, Chile, Colombia, Ecuador, French Guiana, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela	Costa Rica, El Salvador, Honduras, Mexico, Nicaragua, Panama	Antigua and Barbuda, Bahamas, Barbados, Bermuda, Cuba, Dominica, Dominican Republic, Grenada, Guadeloupe, Jamaica, Martinique, Puerto Rico, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago	USA	EPPO, 2016
S. exigua (non-native)	Scarce[2]	Present	Present	Canada, USA	CABI, 2016
S. frugiperda	Bolivia, Brazil, Chile,	Belize, Costa Rica, El	Anguilla, Antigua and Barbuda,	USA,	EPPO, 2016; OMAFRA,

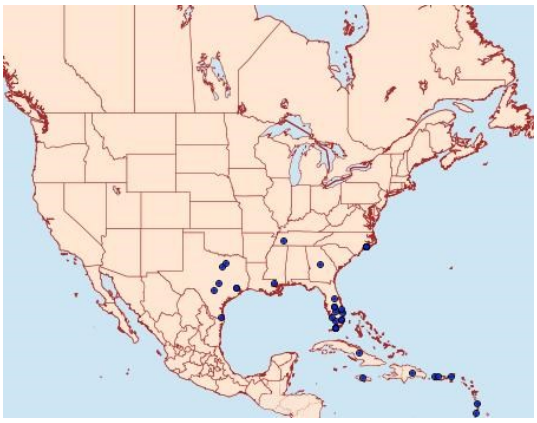
Spodoptera sp.	South America	North America			References[1]
		Central America and Mexico	Caribbean and Bermuda	Canada, USA	
	Colombia, Ecuador, French Guiana, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela	Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama	Bahamas, Barbados, Bermuda, Cayman Islands, Dominica, Dominican Republic, Grenada. Guadeloupe, Haiti, Jamaica, Martinique, Montserrat, Puerto Rico, St. Kitt andNevis, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago, U.S. Virgin Islands,	In Canada summer migrants	2009
S. latifascia	Probably not present[4]	Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua,	Antigua, Bahamas, British Virgin Islands, Dominica, Dominican Republic, Grenada, Haiti, Jamaica, Puerto Rico, St. Kitt andNevis, St. Lucia, U.S. Virgin Islands	USA	Patterson, 2014; Pogue, 2002; Remillet, 1988; Young et al., 2013
S. ochrea	Ecuador, Peru, Chile	No records found	No records found	No records found	Young et al., 2013; Angulo & Jana, 1982; NVWA-interception on produce from Peru.
S. ornithogalli	No records found	Costa Rica, Guatamala, Honduras, Mexico	Antigua, Bermuda, Cuba, Dominica, Dominican Republic, Haiti, Jamaica, Puerto Rico	Canada, USA	Karsholt, 1994; Pogue, 2002; Young et al., 2013
S. praefica	No records found	No records found	No records found	Canada, USA	Patterson, 2014; Young et al., 2013,
S. pulchella	No records found	No records found	Bahamas, Cuba, Cayman Islands, Dominican Republic, Jamaica, Puerto Rico	USA[2]	Patterson, 2014; Pogue, 2002; Young et al., 2013

[1] The list is based on a broad array of sources available to us, but may be not fully complete; especially older literature from South America is difficult to access.

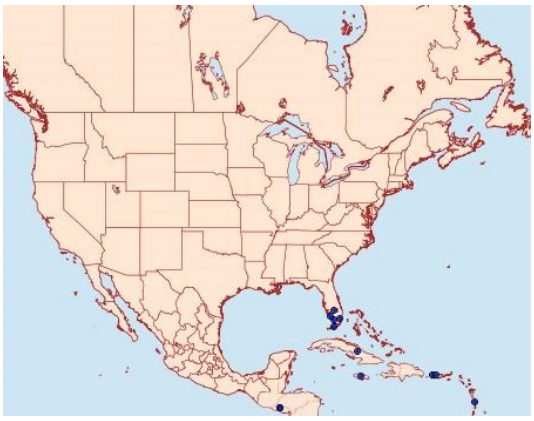
[2] Florida only

[3] The presence of *S. exigua* in South America is uncertain. Some sources report it absent (CABI, 2016; Capinera, 2008), other sources *assume* it present (Young et al. 2013). The only reliable record known to us is from French Guiana (Todd & Poole, 1980). *Spodoptera exigua* is most likely present in very low densities in the northern part of South-America.

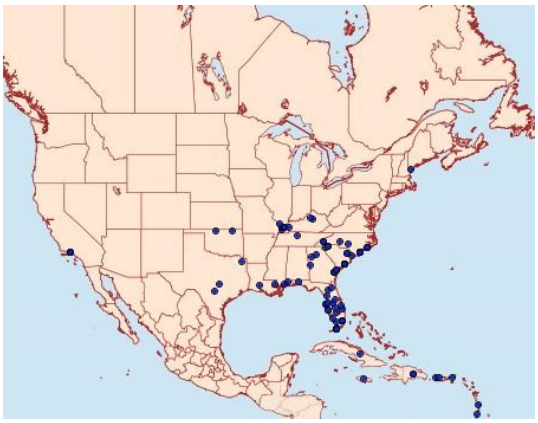
[4] Reported from French Guiana (Remillet, 1988). However, it is likely that the record from French Guiana concerns either *S. cosmioides* or *S. descoinsi*: after 1988, *S. descoinsi* was described from French Guiana as a sister species to *S. latifascia* and *S. cosmioides* was re-instated as species, after being considered a synonym for *S. latifascia* for some time.



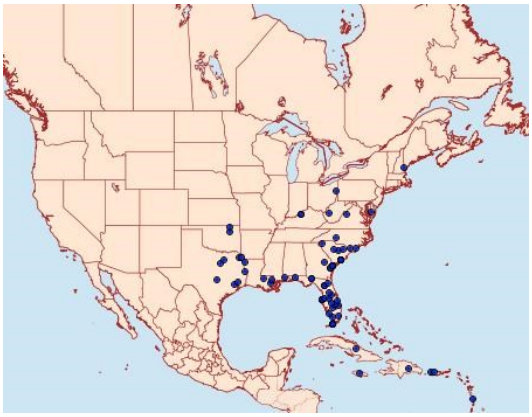
Spodoptera albula



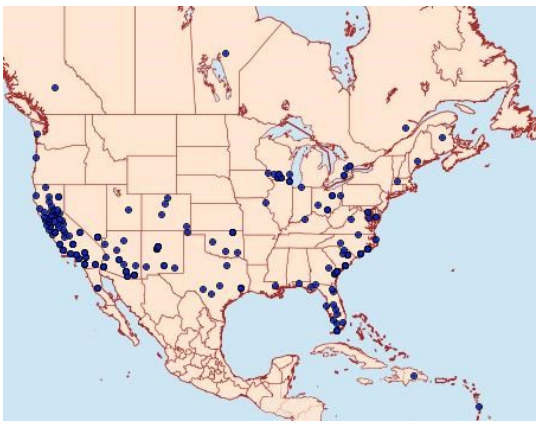
Spodoptera androgea



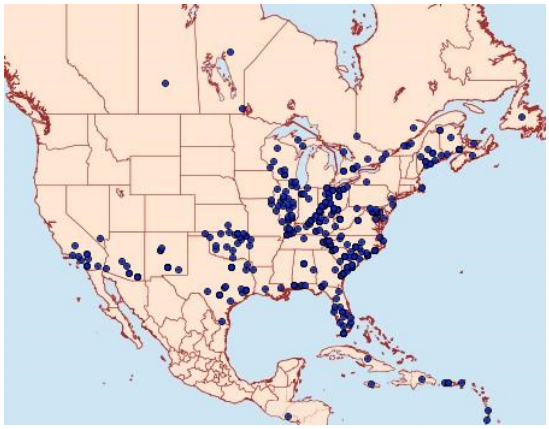
Spodoptera dolichos



Spodoptera eridania

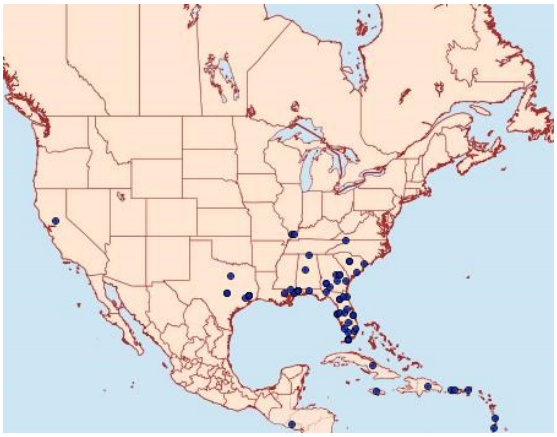


Spodoptera exigua

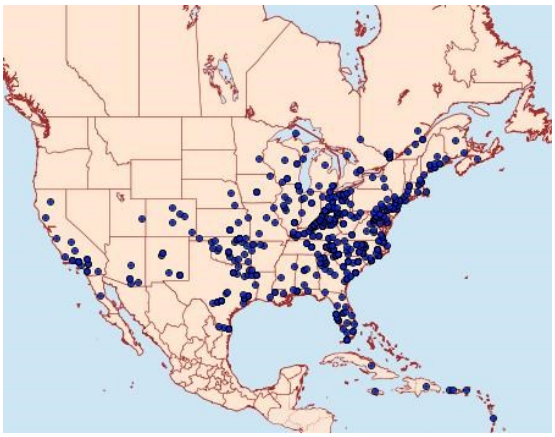


Spodoptera frugiperda

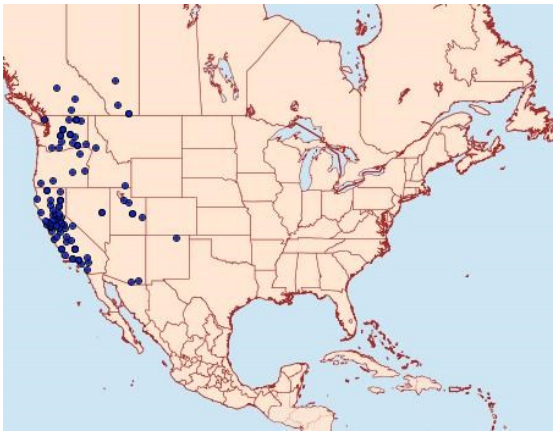
Fig. 4.1. Records of findings of 10 *Spodoptera* spp. in North America. Please note that a finding does not necessarily indicate that the species is present at that place throughout the year. Many species may only overwinter in more southern areas and migrate to more northern areas during summer (see also the text). Source: http://mothphotographersgroup.msstate.edu/ [accessed 21 June 2016]



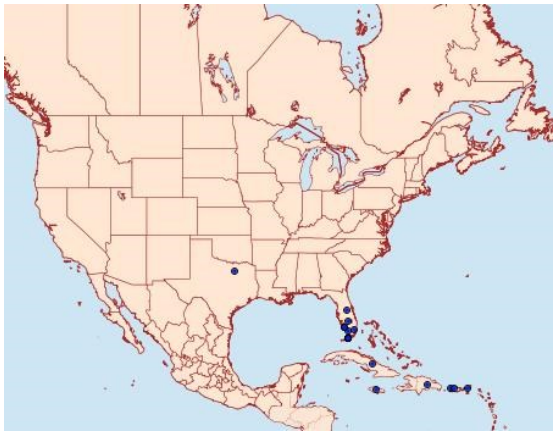
Spodoptera latisfascia



Spodoptera ornithogalli



Spodoptera praefica



Spodoptera pulchella (The record from Texas may not be reliable).

Fig. 4.1 (continued from page 19). Records of findings of 10 *Spodoptera* spp. in North America. Please note that a finding (blue dot) does not necessarily indicate that the species is present at that place throughout the year. Many species may only overwinter in more southern areas and migrate to more northern areas during summer (see also the text). Source: http://mothphotographersgroup.msstate.edu/ [accessed 21 June 2016]

5. Potential area of distribution

Most American *Spodoptera* species are polyphagous and their host plants are widespread in the EU. Generally, it is expected that most species can overwinter in at least the southernmost parts of the EU and several may migrate to more northern areas during summer. Many species are present in North America where they overwinter in the southern USA but the exact limit of their overwintering sites is not known and may also vary from year to year depending on the weather (see Chapter 4). The plant hardiness zones in the southern EU are comparable to those in southern USA, 9 and 10 (Fig. 5.1) which indicate that winter temperatures will not be the limiting factor for establishment of these species. Establishment of *Spodoptera* species will, however, depend on several factors. High soil moistures, for example, negatively affects survival of prepupae and pupae of *S. exigua* and this may also be the case for other S*podoptera* spp. (Zheng et al., 2012, 2013). Besides survival percentages during winter, population development during summer is important for establishment. The number of winter survivors will be the net result of population increase during summer and population decline during winter and the conditions for *Spodoptera* spp. in the EU may generally be less favourable than in the USA because of lower temperatures during the summer season (Fig. 5.2). Unlike *S. exigua*, the American *Spodoptera* species are not known as significant greenhouse pests in temperate climates (i.e. in areas where the species cannot establish outdoors). Therefore, outbreaks or transient populations may occur in commercial greenhouses but the species are not expected to establish in commercial greenhouses or become significant greenhouse pests. They might be able to establish in tropical greenhouses, e.g. in zoos and botanical gardens where the climate may be more suitable for establishment (suitable conditions throughout the year) and where pesticides are usually not applied or much less intensively to control pests than in commercial greenhouses. The potential area of distribution of the different American species outdoors is discussed in more detail below.

Spodoptera albula, S. androgea, S. pulchella, S. cosmioides and *S. ochrea*

S. albula, S. androgea and *S. pulchella* are found in a limited part of southeastern USA and seem to prefer tropical conditions (Fig. 4.1). According to Heppner (1998) findings of these species in southeastern USA may be strays from the Caribbean. Populations may, however, build up over years and/or conditions may become more favourable due to climate change. Recently, *S. albula* was noticed as a pest in a strawberry field in central Florida (pers. comm. R.L. Meagher, USDA-ARS, Florida). However, also taking into account that temperatures in southern EU are generally lower than in Florida (Fig. 5.2), these species are not expected to find favourable conditions in Europe and their potential area of distribution may be very limited. This is probably also the case for *S. cosmioides* and *S. ochrea* that are only known to be present in tropical areas. *S. ochrea* has been reported from the dry west coast of Ecuador, Peru and (the extreme north part of) Chile.

Spodoptera dolichos, S. eridania, S. frugiperda and *S. latifascia*

In the USA, *S. dolichos, S. eridania, S. frugiperda* and *S. latifascia* most likely survive the winter season in the very southern states and (most) findings in more northern areas are likely due to summer migration from southern states although the exact overwintering sites are not known (Chapter 4). It is assumed that *Spodoptera dolichos, S. eridania, S. frugiperda* and *S. latifascia* can survive the winter outdoors in southern Europe in areas with the same plant hardiness zones (zones 9-10; Fig. 5.1). Their overwintering sites may be similar to those of *S. exigua* and *S. littoralis* in southern Europe (EFSA-PLH, 2015; Zheng et al., 2012). *Spodoptera exigua* also overwinters in greenhouses in more northern regions, both in Europe (Malais & Ravensberg, 1992) and probably also in North-America but no indications/reports have been found that *S. dolichos, S. eridania, S. frugiperda* and *S. latifascia* overwinter in greenhouses in cooler climates. *Spodoptera dolichos, S. eridania, S. latifascia* and especially *S. frugiperda* may migrate to more northern areas during summer (Fig 4.2). Seasonal migration of *S. frugiperda* occurs from southern USA up to Canada (e.g. Westbrook et al., 2016).

Spodoptera ornithogalli

S. ornithogalli may be able to establish (being present year round) in more northern areas in the EU than the other *Spodoptera* species (see also Chapter 4). According to Fleischer (2012), it

overwinters as pupae in soil in North Carolina and Kentucky. These states have plant hardiness zones of 7-8 and 6-7, respectively (http://planthardiness.ars.usda.gov/, accessed 21 June 2016). Therefore, *S. ornithogalli* may potentially overwinter up to southern Sweden and in parts of eastern Europe (Fig. 5.1). However, spring and summer temperatures in these areas are much less favourable for population development than in North Carolina and Kentucky (Fig. 5.2). Temperature requirements for the completion of one life cycle were not found for *S. ornithogalli* in literature. For some of the other Spodoptera species, data are, however, available. For example, females and males of *S. exigua* need about 490 and 543 degree days base 12.2°C, respectively (Hogg & Gutierrez, 1980). In the central part of the Netherlands, the number of degree days varied between 610 and 899 base 12.2°C from 2000 to 2010 (weather data from De Bilt, KNMI on https://projects.knmi.nl/klimatologie/daggegevens/). Thus, *S. exigua* can normally not complete more than one life cycle outdoors in the Netherlands. It seems unlikely that temperature requirements for *S. ornithogalli* differ from that of *S. exigua* enough to result in two generations per year in the Netherlands and other European countries with similar summer temperatures (Fig. 5.2).

Spodoptera praefica

Like *S. ornithogalli, S. praefica* may also be able to establish in more northern areas but also for this species data are lacking on the conditions needed for overwintering (see Chapter 4).

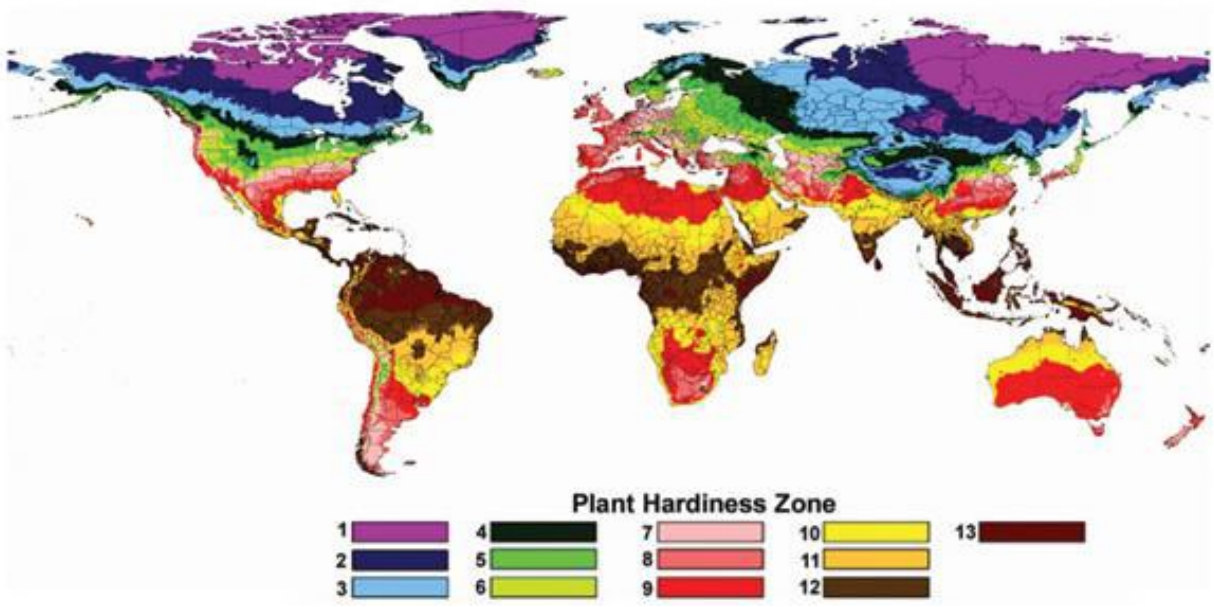


Fig. 5.1 Global hardiness zone map for the period 1978-2007 (Magarey *et al.,* 2008)

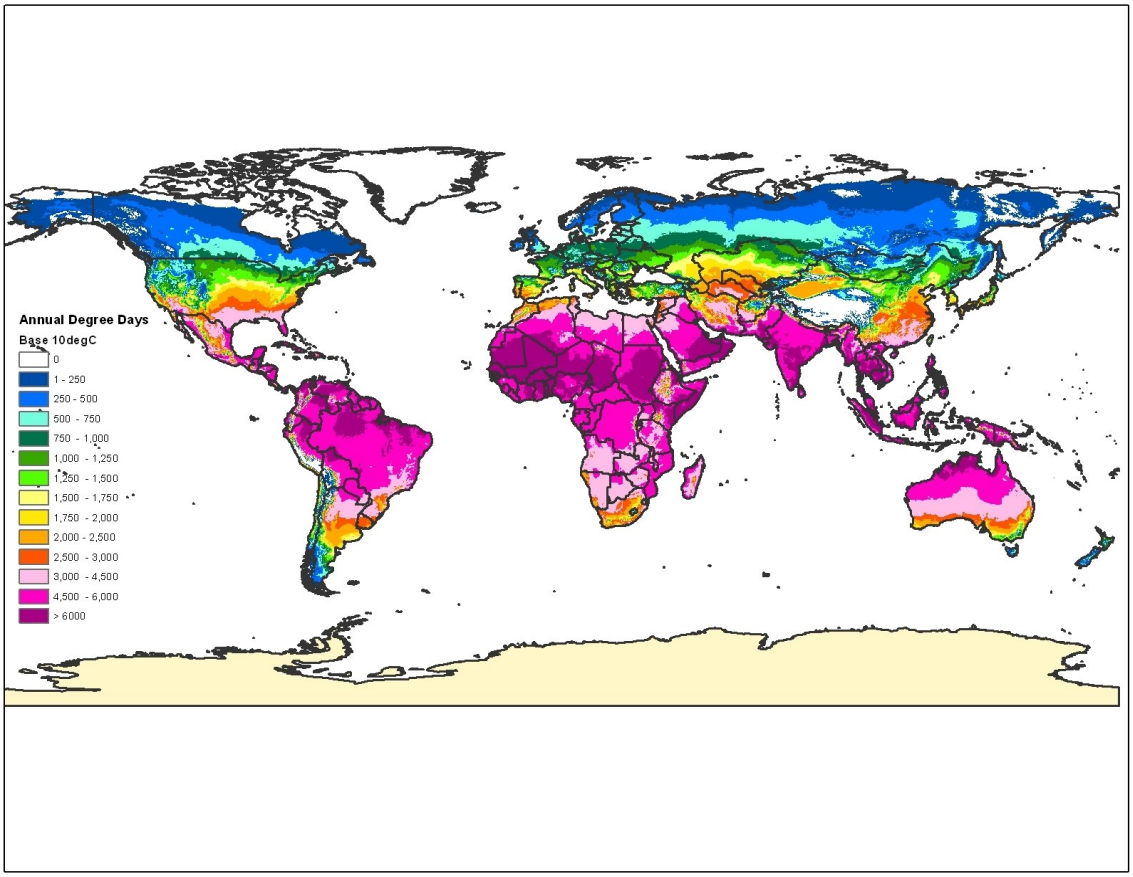


Fig. 5.2. World map of temperature accumulation (Degree Days) based on a threshold of 10°C using 1961-1990 monthly average maximum and minimum temperatures taken from the 10 minute latitude and longitude Climatic Research Unit database (New et al., 2002). Maps were kindly provided by R. Baker, FERA, and previously used in the EFSA-project Prima Phacie (Macleod et al., 2012). Similar maps based on the same information but with different degree day intervals were published in 2002 and 2012 (Baker, 2002; Eyre et al., 2012).

6. Economic impact

6.1 What is the economic impact of the pest in its current area of distribution?
Spodoptera spp. damage crops mostly by larval feeding on leaves and stems. Larvae may also feed on fruit. The impact of the different species in the current area of distribution is discussed below.

S. albula (syn. S. sunia)
S. albula has been described as a tropical armyworm and of little economic importance in Florida (Heppner, 1998). In the Caribbean, Central and South America, *S. albula* is considered a pest of several crops. Little quantitative information was found on yield or quality losses; examples of statements in literature about their economic importance as a pest are given below for different regions.

Canada, USA
S. albula is of little economic importance in Florida (Heppner, 1998). Wagner et al. (2012) stated: "While the species is occasionally destructive to crops in Central America, it is not a pest in the United States. In addition to leaves, caterpillars sometimes damage flowers (cotton) and fruits (tomatoes)." *S. albula* may, however, be a more important pest in Florida than recently known. "It is starting to show up in strawberry fields in central Florida and in high tunnels with strawberries. We don't know the extent of pest pressure yet from this species as most armyworm trouble has been attributed to *S. frugiperda* and *S. eridania*" (pers. comm. R.L. Meagher, USDA-ARS, Florida).

Central America and Mexico
Passoa (1991): "*Spodoptera frugiperda*, *S. exigua*, *S. latifascia*, *S. ornithogalli*, *S. dolichos*, *S. sunia* [*S. albula*] and *S. eridania* are commonly associated with crops in Honduras." Montezano (2014) mentions (referring to other sources): "In many places, especially in Central America, *S. albula* makes it unfeasible to develop important crops such as tobacco [ref…], cotton [ref…], tomato [ref…], cabbage [ref…], sesame, soybean [ref…], peanuts [ref…], sunflower [ref], papaya [ref…] and even seedling production in forestry nurseries [ref….]. The importance of this species is increased by its tolerance to various chemical insecticides and to the *Bacillus thuringiensis* Cry1Ac gene [ref…]. Its importance, motivated studies on its biology [refs…], its damage potential [refs…], and on the identification of pheromonal components for behavioral control [refs…]."

Caribbean and Bermuda,
In St. Kitts [island in the Caribbean], *S. sunia* is considered the major species of Lepidoptera attacking groundnut (Buckmire, 1978). It has been reported to attack tobacco and ripe fruit of strawberry in Cuba and cabbage in Puerto Rico (Armstrong, 1994; Novo Padrino *et al.*, 1984; Vazquez Moreno, 1986). Mellado (1976): "*S. sunia* is a nursery pest of *Pinus caribaea*, *P. tropicalis* and *Casuarina* in Cuba; losses of up to 40% of transplants have been caused by the larvae."

South America
In Colombia, *S. albula* represents together with *S. frugiperda* and *S. ornithogalli* a group of species referred as "the *Spodoptera* complex" of cotton crops" (Saldamando & Marquez, 2012). In Colombia, *S. albula* is also considered a main pest of soybean (Hallman, 1983). (Rolim *et al.*, 2013): "the most important species of Lepidoptera that attack soybean [in Brazil], in descending order of importance, are *Chrysodeixis includens* (Walker), *Anticarsia gemmatalis* Hubner, *Spodoptera cosmioides* (Walker), *Spodoptera eridania* (Stoll), and *Spodoptera albula* (Walker)". In Brazil, *Spodoptera albula* also attacks groundnut (Teixeira *et al.*, 2001). Bergamasco et al. (2013) did research on development of resistance against Bt-plants in *Spodoptera frugiperda*, *Spodoptera albula*, *Spodoptera eridania* and *Spodoptera cosmioides*; it was stated in the introduction that these species are "important pests in Brazil". Field experiments in tomato in Peru testing the efficacy of different pesticides against *S. albula* showed up to 100% economic loss in plots where no control measures were applied (Gloria, 1975).

S. androgea

Few reports of damage caused by *S. androgea* have been found in the literature or on the internet. In Suriname, larvae were found on *Musa* and maize but "damage was negligible since the caterpillars were present incidentally and in small numbers only" (Dinther 1960). In Brazil, larvae have been reported on cacoa (Zucchi & Silveira Neto, 1984). In conclusion, no information was found that *S. androgea* causes significant impact in its current area of distribution.

S. cosmioides

S. cosmioides is present in various countries in South America, Central America and the Caribbean. As a pest, the species is mainly reported from Brazil, where it is considered a serious pest of various cash crops (Moura et al., 2014; Santos et al., 2010; Teodoro et al. 2013). Quantitative information on the impact of *S. cosmioides* has not been found. It is often mentioned together with other pests causing similar symptoms and has been reported as one of the most important pests on soybean (*Glycine max*). On soybean, the feeding capacity of *S. cosmioides* was shown to be nearly twice the capacity of other common lepidopteran pests including *S. frugiperda* (Freitas Bueno et al., 2011). *S. cosmioides* is also known as a pest in soybean in Argentina and Uruguay (Blanco et al., 2016). In Brazil and Argentina, *S. cosmioides* appeared to be much less susceptible to the control effects of *Bt* soybean than other common Lepidoptera species in this crop (Bernardi *et al.*, 2014; Blanco et al., 2016; Silva et al., 2016). In Venezuela, *S. cosmioides* was found for the first time on strawberry in 2012, but not in densities causing economic damage (Solano et al., 2015).

S. dolichos

Available information on *S. dolichos* as a pest is very limited. There are few notes of this species attacking plants. According to Heppner (1998), *S. dolichos* has a shorter list of known host plants than the other pest species of *Spodoptera* and it favours sweet potato (*Ipomoea batatas*). However, the NPPO of the Netherlands has intercepted the species on various products: fruit of *Momordica, Capsicum* and *Solanum macrocarpon* and leafy vegetables of *Apium graveolens* and *Cestrum,* all from Suriname and on plants for planting of *Dichorisandra thyrsiflora* from the USA. It cannot be concluded from these interceptions that *S. dolichos* is a significant pest on these crops but they indicate that *S. dolichos* has a fairly wide host range. Teixeira & Yokomizo (1987) reported that seedlings of two *Pinus* species were badly damaged by larvae of *S. dolichos* in a greenhouse in Sao Paulo (Brazil). Sanchez Soto (2000) found *S. dolichos* on tabasco in Mexico but did not report on economic damage. Solano *et al.* (2015) reported the finding of four Lepidopteran species on strawberry in Venezuela including three *Spodoptera* species: *S. dolichos, S. cosmioides* and *S. frugiperda*. It was concluded that the species could be potential pests on strawberry crops in Venezuela. In the USA, *S. dolichos* rarely causes damage on vegetables, including sweet potato (Capinera, 2002). Tygesen (1967) reported an outbreak with 200 – 300 larvae of *S. dolichos* in a greenhouse in Denmark on *Citrus* plants imported from Florida (note: the original identification of *S. ornithogalli* was corrected in 1985 (Karsholt, 1994). The outbreak was eradicated.

S. eridania

S. eridania is a pest of various crops in the Americas and the Caribbean including sweet potato, tomato and pepper (e.g. Capinera, 2014c). In Florida (USA), it can cause significant losses in tomato together with *S. ornithogalli* (Liburd *et al.*, 2000); see *S. ornithogalli* for details. In the USA, it is mainly a pest in southeastern states; although reported from California it is not a problem there (Capinera, 2014c). Natural occurring natural enemies, especially predators, may affect populations of *S. eridania* but this seems undocumented (Capinera, 2014a).

S. exigua

S. exigua originated in Southeast Asia but is now present in many areas of the world including Europe and North America. It has been included in the present study for comparison. There are thousands of papers about this pest in literature and it is the only *Spodoptera* species mentioned as a regular greenhouse pest in areas where it cannot establish outdoors. Insecticide resistance is

considered a major problem in the control of the species (e.g. Capinera, 2014d; Groenkennisnet, 2016; Lasa *et al.*, 2007; Moulton *et al.*, 1999).

Canada, USA
The USDA (Ellis, 2004) lists *S. exigua* as a *Spodoptera* species "of economic importance". In the USA, *S. exigua* is mainly a pest in southern states of the USA and in greenhouses; in Florida, it is considered a serious pest of flower crops and cotton (Capinera, 2014d). The estimated losses in nine southeastern states was on average approximately $11 million per year during the period 1975-1983 which was much less than for *S. frugiperda* and five other migratory Lepidoptera species (Sparks, 1986). In tomato, larval populations did not exceed the economic threshold level in field experiments (Liburd *et al.*, 2000). Zalom *et al.* (1986) did not find fruit damage nor economic damage in tomato plants deliberately infested with larvae or egg masses of *S. exigua* in California. Research from Ehler (2004, 2007) indicates that a complex of native predators and parasites and especially generalist predators significantly contribute to the suppression of *S. exigua* field populations in sugar beet and hay alfalfa in northern California.

Central America and Mexico
Osorio et al. (2008) mention *S. exigua* as "the second most destructive insect pest of pepper and tomato" in the north-west and central region of Mexico where it "is responsible for an estimated 20-25% of the total yield losses attributed to insects". Aragon Garcia et al. (2011) found *S. exigua* among the pests causing considerable damage in *Amaranthus hypocondriacus* during a survey in the semiarid region Mixteca of Puebla State in Mexico.

Caribbean and Bermuda
In the Caribbean, *S. exigua* has been indicated as one of the major pests on *Amaranthus* spp. together with *S. frugiperda* and *S. eridania* (Clarke-Harris *et al.*, 2004). Data from a field experiment did not indicate if the three species were equally important on *Amaranthus*. Armstrong (1994) reported *Spodoptera exigua* and *S. frugiperda* attacking cabbage in an experimental field in Puerto Rico but the amount of damage (i.e. % yield loss) was not indicated. In St. Kitts and Nevis, *S. exigua* (and *S. frugiperda*) is sometimes a problem in groundnut, while *S. sunia* [*S. albula*] is the major species attacking the crop (Buckmire, 1978).

South America
The presence of *S. exigua* in South America is not clear. There are interception records (Young et al., 2013) and some (secondary) references in literature (Zheng et al., 2011). Capinera (2008) and CABI (2016), however, consider *S. exigua* as absent and Pogue (2002) states that *S. exigua* is rare or absent in South America. Due to similar morphology of the larvae it is possible that larvae of *Copitarsia* species, a common pest species group in South America, have been misidentified as *S. exigua,* leading to incorrect records of *S. exigua.* Apart from the report from French Guiana (Todd & Poole, 1980) there are no reports known to us of *S. exigua* being collected in the field in South America and we have not found any reports of economic damage caused by *S. exigua* in South America.

Europe
In southern Europe, *S. exigua* is a pest of various crops. It is considered a major pest of sweet pepper, aubergine, courgette, melon and watermelon crops in greenhouses in Almeria in southern Spain (Moreno et al., 1992 in Lasa *et al.*, 2007). Quantitative information on yield losses is, however, scarce. Sannino *et al.* (2007) reported that 30-40% of the area cultivated with summer melon and watermelon crops was damaged by four Lepidopteran species including *S. exigua* in some areas in Italy in 2006. Approximately 60% of the plants in infested fields showed damage on fruits and leaves. Larvae of *Helicoverpa armigera* and *S. exigua* mostly bored through the fruits while larvae of two other species usually fed on the fruit surface. Sannino *et al.* (2004) reported heavy infestations in many field and greenhouse crops in Italy in 2003, probably due to the unusual warm summer weather, with the most destructive species being *Helicoverpa armigera, S. littoralis, S. exigua* and *Ostrinia nubilalis.* Unusual infestations with *S. exigua* were also reported for onion in Italy in 2003 (Manucci *et al.*, 2003). In Dutch greenhouses, *S. exigua* can cause damage in various crops (Groenkennisnet, 2016). However, quantitative data on yield losses (including losses of marketable products) and control costs have not been found for the Netherlands.

According to crop protection specialists, *S. exigua* was an important greenhouse pest in the Netherlands in the 1980s and 1990s, but due to newly developed pesticides, *S. exigua* is currently an occasional and minor pest (Information from consultants from Delphy, (Wageningen, the Netherlands) and Koppert B.V. (Bleiswijk, the Netherlands)).

S. frugiperda

S. frugiperda is a pest of various crops in the Americas. There are thousands of papers about this pest in literature. It is considered a major pest of maize, sorghum, rice and sugar cane but it is a polyphagous pest that can attack many more species (e.g. Fernandes *et al.*, 2012; Kondidie, 2011; Zhang *et al.*, 2016). Among seven migratory Lepidopteran pest species, *S. frugiperda* was estimated to be the second most important pest in nine southeastern states in the USA with an average annual yield loss of $60 million in the period 1975-1983 (Sparks, 1986). See also Kondidie (2011) for an overview of the economic importance of the pest. It is a regular and serious pest in the southeastern states of the USA (Capinera, 2014b). It can also cause significant economic damage in more northern states depending on the time of pest arrival. In Pennsylvania, *S. frugiperda* is a pest that regularly needs control measurements to prevent economic damage e.g. on sweet corn and occassionally on tomato although insecticide sprays already applied against other Lepidopteran pest also control *S. frugiperda* (Penn State Univ, 2012; pers. comm. S. Fleischer, Pennsylvania State University). OMAFRA (2009) advises on threshold levels to take action against *S. frugiperda* in corn in Ontario (Canada) and states: "sprays used for corn borer [*O. nubilalis*] and corn earworm (*Helicoverpa zea*) usually control the armyworm as well." *S. frugiperda* has many natural enemies but they generally do not seem to play a major role in the suppression of the pest in Florida and more northern regions; predation of generalist predators may locally lead to significant losses in the number of surviving pupae (Capinera, 2014d).

The species is known to prefer Poaceae and two strains of *S. frugiperda* are differentiated: a "corn strain" and a "rice strain" that differ in host range, genetics and wing shape (e.g. Cano-Calle *et al.*, 2015). The "corn strain" prefers corn and sorghum and the "rice strain" rice, turf grass and alfalfa. However, the species is highly polyphagous and serious damage has also been reported from dicot crops, for example, from onions that were grown adjacent to a maize crop genetically modified to protect it from *S. frugiperda* in Brazil (Fernandes *et al.*, 2012). In the Netherlands *S. frugiperda* is intercepted regularly from Central and South America on dicots, amongst others *Asparagus, Capsicum, Momordica, Rosa, Solanum macrocarpon* and *S. melongena;* five of the six specimens tested molecularly belonged to the corn-strain.

Recently *S. frugiperda* has been discovered in West- and Central-Africa where outbreaks were recorded for the first time early 2016. After what seems are multiple introductions, the species is expected to colonize most of tropical Africa (Goergen et al, 2016). Early 2017 *S. frugiperda* was reported for the first time from South Africa (DAFF, 2017) and has now also been reported from parts of East Africa including Kenya (CABI, 2017). Given its migratory nature (OMAFRA 2009) *S. frugiperda* may reach southern Europe by natural spread within some years although the Sahara desert may slow down its natural spread to northern Africa and Europe.

S. latifascia

Spodoptera latifascia is considered a pest in certain areas of its distribution. It has been reported as a common species in Florida (Heppner, 1998), and is known to cause regular damage mostly in private gardens and homegrown vegetables, and incidentally in commercial grown ornamentals (USDA-APHIS diagnostic data; pers. comm. J. Brambila). Occasionally larvae are being found in greenhouses, as the moths are being attracted to light, but there are no reports of correlated damage (pers. comm. R.L. Meagher, USDA-ARS, Florida). It is not considered an important pest in commercially grown crops and there are only a few reports of actual damage (e.g. Musgrave *et al*., 1979). In tropical areas, however, it is considered an important pest, for example on lettuce and tomato in Costa Rica, on corn and tomato in Honduras and on cotton in Barbados and Honduras (Pogue 2002). In the Greater and Lesser Antilles, it is frequently found on vegetable crops (tomato

and egg-plant) (Zagatti 1995). Thus, economic damage so far seems to be limited to tropical climates. Quantitative data of yield losses are, however, lacking.

S. ochrea

Little information is available on the impact of *S. ochrea*. Research on control options suggests that it is a known pest of tomato and asparagus in the coastal areas of Peru (Luna Rodriguez et al., 2002; Castillo-Valiente & Castillo-Oliva, 2004). Luna Rodriguez *et al.* (2002) reported that application of the nucleopolyhedrovirus resulted in a reduction of 80% of pest populations in tomato crops infested by *S. eridania* and *S. ochrea*. The authors mention in the introduction that *S. ochrea* is the main defoliator in tomato crops in the coastal areas of Peru. The USDA considers *S. ochrea* as one of the minor *Spodoptera* pests (Ellis, 2004).

S. ornithogalli

Canada, USA S. ornithogalli is mentioned as a pest on various crops including tomato, cotton and maize in the USA (e.g. Armstrong *et al.*, 2011; Forde *et al.*, 2009; Liburd *et al.*, 2000). In the USA, the species survives winter in southern states but migrants may reach northern states during summer (see Chapter 4 for details). As a pest, its occurrence is mainly limited to the southeastern states. Incidentally, damage may occur in more northern states. Fleischer (2012) reported tomato fruit damage by *S. ornithogalli* in Pennsylvania in 2012 possibly due to the fact that the winter of 2011-2012 was very warm and the species had overwintered closer to Pennsylvania than in normal years. According to Capinera (2014a), the species is not a problem in California. Liburd et al. (2000) tested several insecticides against naturally occurring *Spodoptera* spp. in tomato field experiments in 1991 and 1992 in Florida. Population densities of *S. ornithogalli* and *S. eridania* exceeded the economic threshold of 0.7 larvae/4 plants prebloom but that of *S. exigua* did not. Various insecticides applied against *Spodoptera* larvae significantly increased tomato marketable fruit yield up to 73.5%. Kennedy *et al.* (1983) studied pests that directly affected tomato fruit in the Coastal Plain of North Carolina in 1979 and 1980. They found *S. ornithogalli* causing minor injury to the fruit only in the late planting of 1979. In Kansas, *S. ornithogalli* (and *S. exigua*) may attack forage but seldom reach pest status (Loftin et al., 2017). Little information is available on damange in greenhouse crops. In Florida, larvae are occasionally found in greenhouses, as the moths are being attracted to light, but there are no reports of correlated damage (pers. comm. R.L. Meagher, USDA-ARS, Florida). Presence of natural enemies, especially predators, may affect populations of *S. ornithogalli* but their impact has not been quantified (Capinera, 2014a). The USDA lists *S. ornithogalli* as a *Spodoptera* species "of economic importance" (Ellis, 2004).

Central America, Mexico, Caribbean, Bermuda, South America

Outside the USA, *S. ornithogalli* is known as a species feeding on several crops but quantitative information on impact is missing. Passoa (1991): "*Spodoptera frugiperda*, *S. exigua*, *S. latifascia*, *S. ornithogalli*, *S. dolichos*, *S. sunia* [*S. albula*] and *S. eridania* are commonly associated with crops in Honduras." Quimbayo *et al.* (2010) identified *S. ornithogalli* together with several other noctuid species on flower farms in Colombia but the damage caused by the species was not indicated. The species is often mentioned as part of the *Spodoptera* complex attacking a crop. In Colombia, *S. ornithogalli* attacks maize to a lesser extent than *S. frugiperda* (Ruppel et al., 1957). In an old report, *S. ornithogalli* is mentioned as causing serious injury to tobacco in Jamaica (Gowdey, 1923).

S. praefica

S. praefica is a common species in the western USA where it is known as a pest on various crops including tomato, lupin, rice, lucerne and lentil (e.g. Babcock *et al.*, 1993; Benedict & Cothran, 1980; Grigarick, 1984; Halfhill, 1982; Nandwani, 2013).

California

Bisabri-Ershadi & Ehler (1981) indicated that *S. praefica* is an occasional pest of alfalfa, cotton, sugar beet and tomato and that periodic outbreaks occur on hay alfalfa in northern California. In a field experiment with alfalfa, control of larvae of *S. praefica* and *S. exigua* did not result in higher

yield levels in California (Summers, 1989). Generalist predators may keep populations of *S. praefica* and *S. exigua* in hay alfalfa in northern California at relatively low levels (Bisabri-Ershadi & Ehler, 1981; Ehler 2007). Grigarick (1984) mentions that *S. praefica* reduces panicle development in rice. In tomato, *S. praefica* feeds on foliage and fruit (UC, 2013). "In some seasons, they are the most damaging pest of tomato in the Sacramento Valley [California]" (Anonymous, 1998). The USDA lists *S. praefica* as a *Spodoptera* species "of economic importance" (Ellis, 2004).

Washington
Halfhill (1982) conducted greenhouse and field tests in Washington State to determine the extent of damage caused by *S. praefica* on lentils. When larvae were placed on plants in cages, they did not feed on the foliage but on the pods or cut through the pedicels. It was estimated that one larva per 1,000 cm^2 on lentils with green pods causes approximately 10% crop loss. In practice, the impact will depend on the presence of weed hosts because it was also indicated that in the lentil commercial growing areas, the pest occurs primarily on the weed hosts common to the area and move to the lentils only when their weed hosts are mature or dry. Babcock et al. (1993) mentioned *S. praefica* as one of the major pests of white lupin in eastern Washington but no data on yield losses were indicated.

S. pulchella
Little information is available on this species. It has been described as a tropical armyworm by (Heppner, 1998) and of little economic importance in Florida. It is also called the Caribbean army worm but no reports were found on damage caused in the Caribbean. According to Fife (1939), four armyworms can be present on cotton in Puerto Rico including *Laphygma frugiperda* [*Spodoptera frugiperda*], *S. sunia* [*S. albula*], *Prodenia pulchella* [*S. pulchella*] and *P. dolichos* [*S. dolichos*], "but they seldom if ever become sufficiently numerous to be of economic importance".

Conclusions on economic impact of Spododoptera species in the Americas

The economic impact of *Spodoptera* spp. in the Americas varies among the different *Spodoptera* species, host crops and regions (Table 6.1).

Some species are considered pests in (large parts of) their current area of distribution including the USA although quantitative data on yield losses are generally lacking. These species are:

- *S. eridania*
- *S. exigua*
- *S. frugiperda*
- *S. ornithogalli*
- *S. praefica*

These five species are also listed by the USDA as "economically important *Spodoptera*" that are "prevalent in the continental U.S." (Ellis, 2014). From these species, *S. exigua* is the only one known as a regular greenhouse pest in areas where the pest cannot establish outdoors.

Some species are considered pests in tropical areas of their distribution but no written reports have been found on economic impacts caused by these species in the USA:

- *S. albula*
- *S. latifascia*

S. albula may, however, be a significant pest in strawberry cultivation in Florida or its importance is increasing. Problems in strawberry with Lepidopteran pests may have thus far been attributed to other *Spodoptera* spp. of which larvae and adults look very similar.

Some species have been reported as (important) pests in a few countries only (these species are not present in North America):

- *S. cosmioides* (Brazil)
- *S. ochrea* (Peru)

The pest status of *S. dolichos* is highly uncertain. In the USA it is not known as a significant pest but a few outbreaks have been reported from other countries.

Two species seem of little economic importance in their current area of distribution:

- *S. androgea*
- *S. pulchella*

Table 6.1. Pest status of 12 *Spodoptera* spp. in various regions of America (see text for references)

Spodoptera sp.	**Mexico, Central America, Caribbean, South America**	**USA**		
		Southeastern states	**Southwestern states**	**Other states**
S. albula	Pest on various crops	Present in Florida. Recently observed causing damage in strawberry but no written reports on economic damage	Not known to be present	Not known to be present
S. androgea	No reports on significant damage	Present in southern Florida but not known as a pest	Not known to be present	Not known to be present
S. cosmioides	Pest in Brazil, Argentina and Uruguay	Not known to be present	Not known to be present	Not known to be present
S. dolichos	Very few reports, may be an occasional pest	No reports on crop damage; indicated as a rare pest on vegetables.		
S. eridania	Pest on various crops	Pest on various crops	Mainly a pest in southeastern states	Mainly a pest in southeastern states
S. exigua	Pest on various crops	Pest on especially ornamentals and cotton.	Pest in southern states	Greenhouses
S. frugiperda	Pest on various crops (prefers Poaceae)	Pest on various crops (prefers Poaceae). Recognized as the economically most important *Spodoptera* sp. in SE-USA	Mainly a pest in southeastern states	Less of a pest than in southeastern states, pesticides applied against other caterpillars normally control *S. frugiperda* as well.
S. latifascia		Present in Florida but not known as a pest on commercially grown crops.		
S. ochrea	Pest in Peru	Not known to be present	Not known to be present	Not known to be present
S. ornithogalli	Considered as a pest on several crops	Pest on various crops	Present but not a problem	Transient/incidental
S. praefica	Not known to be present	Not known to be present	Pest on various crops	Known as a pest in western USA
S. pulchella	No reports on significant damage	Present in Florida but not known as a pest	Not known to be present	Not known to be present

6.2 What is the endangered area and the expected direct economic impact? *(with the use of control measures)*

It is assessed that *S. eridania, S. frugiperda*, *S. ornithogalli* and *S. praefica* are potentially most damaging and the other species (*Spodoptera albula*, *S. androgea*, *S. cosmioides*, *S. dolichos*, *S. latifascia*, *S. ochrea* and *S. pulchella*) are of minor importance for the EU. This assessment is based on the known distributions of the species in the Americas and their impacts recorded in the more northern parts of the Americas especially the USA (see 6.1). Five of the species (*S. albula*, *S. cosmioides*, *S. dolichos*, *S. latifascia* and *S. ochrea*) are known as pests in tropical regions. *S. cosmioides* has for example been indicated as an important pest in Brazil but only to a lesser extent from other countries (see 6.1). It seems especially a pest of tropical regions and has not been listed as an "economically important *Spodoptera*" by the USDA (Ellis, 2014). The species might be a threat for tropicial non-commercial greenhouses (e.g. zoos and botanical gardens). Two species (*S. androgea* and *S. pulchella*) do not seem of economic importance in their current area of distribution at all (see 6.1). The four species that are considered of economic importance for the EU, *S. eridania, S. frugiperda*, *S. ornithogalli* and *S. praefica,* are also considered of economic importance by the USDA (Ellis, 2014). These four species are discussed in more detail below.

<u>*S. eridania, S. frugiperda, S. ornithogalli* and *S. praefica*</u>

Based on the current impacts in the USA (Table. 6.1), *S. eridania* and *S. frugiperda* seem especially a threat to crop production for southern EU member states. Both species can damage many crops. Economically important crops that are expected to be seriously damaged include tomato for *S. eridania* and maize and other Poaceae for *S. frugiperda*. They are not known as (important) greenhouse pests in North America.

S. ornithogalli may overwinter in more northern areas than *S. eridania* and *S. frugiperda* (see 5.1). However, it is only considered a pest of economic importance in the southeastern USA. Hence, the endangered area in the EU may not be much different from those of *S. eridania* and *S. frugiperda* (southern EU member states). The species is polyphagous and is known as a pest of tomato and several other crops.

Like *S. ornithogalli, S. praefica* may overwinter in more northern areas than *S. eridania* and *S. frugiperda.* Findings of the species are known form eastern Washinghton (plant hardiness zone 6 - 7) and Western Canada (Fig. 4.1) although reports on overwintering sites have not been found and the pest may spread northward from the Southwest each year. Economic impacts have mainly been reported from California but the species was shown to cause impacts on lentil grown in cages in Washington (Halfhil, 1982). Cool summers may limit population build up and thereby damage caused by the species. Only in southern regions of the EU the number of degrees days based on a threshold of 10°C is comparable to that in California (Fig. 5.2). Hence, the southern part of the EU is the primary endangered area. Economic impacts may occur more occasionally or to a lesser extent in more northern areas. Tomato and forage crops are among the endangered crops.

Greenhouses

In areas with outdoor populations, *S. eridania, S. frugiperda*, *S. ornithogalli* and *S. praefica* may also enter greenhouses and cause crop damage because several *Spodoptera* species that are present outdoors in Florida may also be found in greenhouses in Florida (see 6.1). However in northern areas further away from their overwintering sites, the species are not expected to become important greenhouse pests because they are not known as such in North America.

Comparison with Spodoptera species already present in Europe (S. littoralis and S. exigua)

The potential impact of *S. eridania, S. frugiperda*, *S. ornithogalli* and *S. praefica* for outdoor crops may be similar to the impacts currently caused by *Spodoptera littoralis* and *S. exigua* with that important difference that *S. frugiperda* especially attacks monocot crops while *S. littoralis* and *S. exigua* are (mainly) known as pests of dicot crops. *S. littoralis* is (like the other species) polyphagous and originates from Africa. In southern Europe, population densities of *S. littoralis* and damage caused by the species vary considerably from year to year (EFSA-PLH, 2015). EFSA-PLH (2015): "In Europe, the impacts caused by *S. littoralis* were minimal until about 1937 [ref…] and

damage has occurred sporadically (but sometimes significantly) ever since". An important difference between *S. littoralis* and the other four species (*S. eridania, S. frugiperda*, *S. ornithogalli, S. praefica*) is, that *S. littoralis* does not migrate over long distances (Campion et al., 1977; Coquempot and Ramel, 2008; Salama & Shoukry 1972; Sarto i Monteys, 1984). Thus, the the endangered area for *S. eridania, S. frugiperda*, *S. ornithogalli* and *S. praefica* is assessed to be greater than for *S. littoralis* because the four species and especially *S. frugiperda* are expected to migrate to more northern areas during summer. The distribution of *S. littoralis* is more limited to the areas where it overwinters.

S. exigua originates in Southeast Asia and is now present in many areas in the world including the USA (and other North American countries) and Europe. Both in the USA and Europe *S. exigua* is especially known as a greenhouse pest. Impacts may vary from year to year but seems generally similar in the USA and Europe; in warmer regions of its distribution (e.g. Mexico), impacts may be higher (see Chapter 6.1 for details). Because *S. eridania, S. frugiperda*, *S. ornithogalli* and *S. praefica* are not known as typical greenhouse pests in the USA (see above), their potential impact for greenhouse crops in the EU is assessed to be lower than that of *S. exigua*. It should, however, be noted that integrated control measures are nowadays available for *S. exigua* which makes this pest much less of a problem than it was before (see Chapter 6.1).

Conclusions
The potential impact of the species, *S. eridania, S. frugiperda*, *S. ornithogalli* and *S. praefica,* is assessed to be generally "medium" for crops in southern Europe (Table 6.2) and generally "minor" for greenhouse crops in northern Europe. "Major" impacts may occur locally or in some years depending on weather conditions. Major impacts may especially occur shortly after introduction of a pest when there is no experience yet to control the pest and control measures already applied against other pests are not sufficient to keep population densities below the economic threshold. In general, the impact will largely depend on measures available to control the pests. If no effective measures are available yield losses may be high. For example, *S. frugiperda* may cause high yield losses in maize in absence of control measures but yield losses may be reduced already by control measures applied to Lepidoptera that are already present, e.g. *Ostrinia nubilalis* and *Helicoverpa armigera* (Meissle et al., 2009). OMAFRA (2009) states about the control of *S. frugiperda* in maize in Ontaria (Canada): "sprays used for corn borer [*O. nubilalis*] and corn earworm [*Helicoverpa zea*] usually control the armyworm as well."

The present assessment is mainly based on information about impacts of the pests in the USA and Canada. Studies in the USA have indicated that natural enemies especially generalist predators seem to keep populations of *S. praefica* and also those of the non-native species *S. exigua* at generally low levels in alfalfa hay (and for *S. exigua* also in sugar beet) (see 6.1). For, *S. frugiperda, S. eridania*, *S. ornithogalli* suppression of populations by naturally occurring predators and parasites have not been documented or quantified. For, *S. frugiperda*, it has been stated that natural enemies generally cannot prevent crop injury (see 6.1). For these reasons (generalist predators or apparently no signficant effect of naturally occurring enemies) it is not expected that the *Spodoptera* species will cause much more damage outside the Americas due to absence of specific natural enemies that may be present in America but not in other areas.

Table 6.2. Rating levels for the potential economic impact, descriptions and score levels for S*. eridania, S. frugiperda, S. ornithogalli* and S. *praefica* (Note that *S. albula*, *S. androgea*, *S. cosmioides*, *S. dolichos*, *S. latifascia*, *S. ochrea* and *S. pulchella* are not included in this table because their impact was assessed to be generally "minor" for Europe).

Rating level	**Description**	**Score[1]**
Minimal	No yield and/or quality losses are expected	
Minor	Yield and/or quality losses are limited **or** The pest can easily be controlled at low costs (costs are lower than average to control pests in the crop)	
Medium	Targeted measures are necessary to keep yield and and/or quality losses limited; crop protection costs are average for the control of pests in the crop	****
Major	Frequent or expensive measures are needed to keep losses limited; significant increase in crop protection costs **or** No effective measures are available and losses are relatively high as compared to losses by most other pests in the crop	*
Massive	Losses are still high after control measures have been implemented **or** No effective measures are available and losses are high **or** Losses are limited after control measures have been implemented but control costs are very high	

[1] Judgment is spread according to the evidence available and belief of the assessors. A total number of 5 '*' is divided among the different rating levels. The most likely rating level get the highest number of '*'. If the assessor is highly certain about a rating level, all 5 '*' can be assigned to that particular rating level. If the assessor is highly uncertain each rating level can be assigned one '*'.

6.3 What is the expected impact on export markets for the PRA area?

For three species (*S. eridania, S. frugiperda* and *S. ornithogalli*) information was found on their regulatory status in non-EU member states in the EPPO Global database (Table 6.3). *S. eridania* and *S. frugiperda* are currently regulated in the EU. More species may, however, be regulated in other countries. *S. eridania* and *S. frugiperda* are regulated species in various countries and if these species were to become established in the EU, it could significantly affect export markets.

Table 6.3. American *Spodoptera* species known as regulated pests (source: EPPO, 2016)

Name	**Region/country**
S. eridania	East Africa, Southern Africa, Israel, Jordan, Uzbekistan, Russia, Turkey, Ukraine, EU
S. frugiperda	East Africa, Southern Africa, Israel, Jordan, Uzbekistan, Russia, Turkey, Ukraine, EU
S. ornithogalli	East Africa, Southern Africa

6.4 What is the expected environmental impact in the PRA area?

Spodoptera species are mainly known as pests of crop plants. The African species *Spodoptera littoralis* and the Asian species *S. exigua* have been introduced into Europe but are not known to cause (much) environmental impact. In general, environmental impact seems much less relevant than impact on commercial crops caused by the *Spodoptera* species. PNM Moths (2017) stated about *S. praefica*: "The species is primarily found in disturbed agricultural areas and urban habitats at low elevations both east and west of the Cascades, and frequently builds up into massive epidemic outbreaks in certain crops such as alfalfa. Adult moths then span out from agricultural areas into surrounding forest and rangeland habitats, but probably do not breed much in more natural, undisturbed habitats," and about *S. exigua*: "It is mostly restricted to disturbed agricultural areas".

Conclusions on impact

Four American *Spodoptera* species seem most relevant for the EU: *S. eridania*, *S. frugiperda, S. ornithogalli* and *S. praefica.* The first two species are listed in Annex IAI of Council directive 2000/29/EC; the latter two species are currently not regulated in the EU. If these species were to be introduced they are expected to cause significant losses in various crops especially in southern parts of the EU.

Other *Spodoptera* species seem of less importance for the EU although there is uncertainty about their potential to establish in the EU and their ability to cause economic damage under European conditions.

7. Uncertainties

The main uncertainties/lack of information in the present PRA are:

- Exact data were missing on overwintering sites, population increases and declines during summer and winter to provide more detailed assessments of the potential areas of distribution and the endangered areas for each *Spodoptera* species. Based on the available data, it is, however, assessed to be likely (low uncertainty) that most species can overwinter in at least the southernmost parts of the EU and may reach more northern areas during summer. The uncertainty is higher for species that are only known from tropical areas in Central and South America, like *S. cosmiodes*. These species might be able to establish in small parts of the southern EU but they are not expected to become significant pests (medium uncertainty).

- The impact of the *Spodoptera* species in the Americas: quantitative impact data were generally lacking and for some species the information was scarce. Therefore, there is some uncertainty about the potential impact of the species for the EU. However, this uncertainty is only medium, because the impact is known of two *Spodoptera* species, *S. exigua* (non-native to Europe) and *S. littoralis* that are present in the EU. Also, for the *Spodoptera* species that are considered most relevant for the EU, more information was available.

- The potential of the *Spodoptera* species to cause impact in greenhouses in northern Europe. From the 18 *Spodoptera* species included in the present study, *Spodoptera exigua* is the only species that is known as a greenhouse pest in temperate climates. Therefore, the other species are expected not to pose a signficant threat to greenhouse crops in areas where the species cannot establish outdoors. They may, however, cause significant impacts in tropical greenhouses (e.g. zoos and botanical gardens). This assessment is, however uncertain (medium uncertainty) also because it is unknown which characteristics makes *S. exigua* a significant greenhouse pest.

- The host range of the *Spodoptera* spp.: the host range may be wider than the plant species on which they have been reported thus far. This uncertainty does not affect the conclusions of the current assessment because the species are already known to attack several important crop species.

- Reports on damage caused by the different *Spodoptera* species must be treated with some caution especially from Central and South America because crop damages observed may have been attributed to the wrong *Spodoptera* species, due to the fact that *Spodoptera* species can easily be misidentified. This uncertainty does not affect the conclusions of the current assessment for the species considered most relevant for the EU because there is little uncertainty about their pest status in the Americas. The impact of the other species in the Americas is more uncertain. However, because these concern mainly tropical species this uncertainty will not greatly affect the conclusions of the potential impact of these species for the EU.

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