Risk analysis report of non-native organisms in Belgium

Risk analysis of the (eastern) gray squirrel *Sciurus carolinensis*

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Etienne Branquart (Cellule Espèces Invasives, Service Public de Wallonie) developed the risk analysis template that was used for this exercise.

The general process of drafting, reviewing and approval of the risk analysis for selected invasive alien species in Belgium was attended by a steering committee, chaired by the Federal Public Service Health, Food chain safety and Environment. RBINS/KBIN was contracted by the Federal Public Service Health, Food chain safety and Environment to perform PRA's for a batch of species. ULg was contracted by Service Public de Wallonie to perform PRA's for a selection of species. INBO and DEMNA performed risk analysis for a number of species as in-kind contribution.

Steering committee members were:

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Rationale and scope of the Belgian risk analysis scheme

The Convention on Biological Diversity (CBD) emphasises the need for a precautionary approach towards non-native species. It strongly promotes the use of robust and good quality risk assessment to help underpin this approach (COP 6 Decision VI/23). More specifically, when considering trade restrictions for reducing the risk of introduction and spread of a non-native organisms, full and comprehensive risk assessment is required to demonstrate that the proposed measures are adequate and efficient to reduce the risk and that they do not create any disguised barriers to trade. This should be seen in the context of WTO and free trade as a principle in the EU (Baker et al. 2008, Shine et al. 2010, Shrader et al. 2010).

This risk analysis has the specific aim of evaluating whether or not to install trade restrictions for a selection of absent or emerging invasive alien species that may threaten biodiversity in Belgium as a preventive risk management option. It is conducted at the scale of Belgium but results and conclusions could also be relevant for neighbouring areas with similar eco-climatic conditions (e.g. areas included within the Atlantic and the continental biogeographic regions in Europe).

The risk analysis tool that was used here follows a simplified scheme elaborated on the basis of the recommendations provided by the international standard for pest risk analysis for organisms of quarantine concern[1] produced by the secretariat of the International Plant Protection Convention (FAO 2004). This logical scheme adopted in the plant health domain separates the assessment of entry, establishment, spread and impacts. As proposed in the GB non-native species risk assessment scheme, this IPPC standard can be adapted to assess the risk of intentional introductions of non-native species regardless the taxon that may or not be considered as detrimental (Andersen 2004, Baker et al. 2005, Baker et al. 2008, Schrader et al. 2010).

The risk analysis follows a process defined by three stages : (1) the <u>initiation process</u> which involves identifying the organism and its introduction pathways that should be considered for risk analysis in relation to Belgium, (2) the <u>risk assessment stage</u> which includes the categorization of emerging non-native species to determine whether the criteria for a quarantine organism are satisfied and an evaluation of the probability of organism entry, establishment, spread, and of their potential environmental, economic and social consequences and (3) the <u>risk management stage</u> which involves identifying management options for reducing the risks identified at stage 2 to an acceptable level. These are evaluated for efficacy, feasibility and impact in order to select the most appropriate. The risk management section in the current risk analysis should however not been regarded as a full-option management plan, which would require an extra feasibility study including legal, technical and financial considerations. Such thorough study is out of the scope of the produced documents, in which the management is largely limited to identifying needed actions separate from trade restrictions and, where possible, to comment on cost-benefit information if easily available in the literature.

This risk analysis is an advisory document and should be used to help support Belgian decision making. It does not in itself determine government policy, nor does it have any legal status. Neither should it reflect stakeholder consensus. Although the document at hand is of public nature, it is important to realise that this risk assessments exercise is carried out by (an) independent expert(s)

[1] A weed or a pest organism not yet present in the area under assessment, or present but not widely distributed, that is likely to cause economic damages and is proposed for official regulation and control (FAO 2010).

who produces knowledge-based risk assignments sensu Aven (2011). It was completed using a uniform template to ensure that the full range of issues recognised in international standards was addressed.

To address a number of common misconceptions about non-native species risk assessments, the following points should be noted (after Baker et al. 2008):

- *Risk assessments are advisory and therefore part of the suite of information on which policy decisions are based;*
- *The risk assessment deals with potential negative (ecological, economic, social) impacts. It is not meant to consider positive impacts associated with the introduction or presence of a species, nor is the purpose of this assessment to perform a cost-benefit analysis in that respect. The latter elements though would be elements of consideration for any policy decision;*
- *Completed risk assessments are not final and absolute. New scientific evidence may prompt a re-evaluation of the risks and/or a change of policy.*

Executive summary

PROBABILITY OF ESTABLISHMENT AND SPREAD (EXPOSURE)

Entry in Belgium	If an introduction of *Sciurus carolinensis* occurs, the risk of establishment of a self-sustaining population in Belgium and neighbouring areas is high because the gray squirrel has a high invasive ability and will find, in Belgium and in the Ecoregion, suitable climatic conditions, habitats and food disponibility in forests, woodlots and parks. Furthermore, only a few individuals are needed to develop a founding population.
Establishment capacity	If an introduction of *Sciurus carolinensis* occurs, the risk of establishment of a self-sustaining population in Belgium and neighbouring areas is high because the gray squirrel has a high invasive ability and will find, in Belgium and in the Ecoregion, suitable climatic conditions, habitats and food disponibility in forests, woodlots and parks. Furthermore, only a few individuals are needed to develop a founding population.
Dispersion capacity	The different models used to predict *Sciurus carolinensis* spread have shown that this species is a very good invader. Dispersal distances during emigration (subadults and juveniles) are of 5-10 km, even when natural connexions are weak (like in the Italian Po-plain). Thus, the gray squirrel has a high dispersal ability. Moreover, because of its strong appeal to humans, and more than many other species, it can cross ecological barriers with some human assistance (translocation into new habitats).

EFFECT OF ESTABLISHMENT

Environmental impacts	It is likely that a gray squirrel establishment in Belgium and neighbouring areas would induce problems of herbivory, particularly because of its bark stripping behaviour in woodland areas which could sometimes lead to ecosystemical changes. Besides that, the problem of exclusive competition with the native red squirrel is particularly worrying in terms of nature conservation. For the most part of the aforementioned authors, *Sciurus carolinensis* clearly drives *S. vulgaris* to extinction where both species co-occur because of competitive exclusion and poxvirus (SPQV) transmission from gray to red squirrels. Where the virus is present, red squirrel displacement is much faster than in areas because *S. carolinensis* is a virus reservoir. Problems of competition with some forest birds could also be due to gray squirrel densities despite there is no strong evidence for it.

RISK MANAGEMENT

Because of the large distances to be travelled, a natural expansion of grey squirrel populations from the British Isles or Northern Italy is unlikely to cause species arrival and establishment in Belgium in the coming years. However, establishment due to escape/release from captive breeding is much more likely to occur. The strengthening of the prohibition of grey squirrel importation, trade and holding already imposed for crop protection and animal welfare purposes could therefore be considered as an efficient measure for reducing the risk of entry to an acceptable level. As a transitional measure, drastic security rules including ear-tagging and systematic sterilization combined with an official surveillance system and the obligation to rapidly report any escape should be imposed for grey squirrels already kept in captivity.

Those preventive measures have to be preferred over early detection and population control as the grey squirrel may easily establish feral populations after escape. Eradication actions are only possible at the very beginning of the invasion process and are difficult to implement because of species low detection rate at low densities, rapid expansion from the release site when suitable ecological conditions are met and strong public opposition towards killing actions.

Résumé

PROBABILITE DE NATURALISATION ET DE DISSEMINATION DANS L'ENVIRONNEMENT

Introduction en Belgique	Il est probable que l'écureuil gris puisse entrer en Belgique par la remise en liberté intentionnelle ou accidentelle d'animaux issus d'animaleries, de zoos ou d'élevages privés (animaux de compagnie). Comme il n'existe pas de population de *S. carolinensis* dans les pays continentaux limitrophes, une expansion naturelle de l'espèce n'est pas envisageable par cette voie dans les prochaines années du moins. Rappelons toutefois que l'espèce est très présente en Grande-Bretagne et qu'en Italie, elle progresse petit à petit vers les Alpes.
Capacité de naturalisation	Si une introduction d'écureuil gris avait lieu en Belgique ou dans les pays voisins, le risque que l'espèce s'établisse et forme une population durable serait élevé car elle trouverait aisément les conditions de vie favorables à son développement dans l'écorégion (climat, habitats et disponibilité alimentaire), et ce, tant dans les forêts que dans les bosquets ou les parcs. De plus, il a été démontré que seuls quelques individus fondateurs suffisent à l'installation d'une population viable d'écureuil gris.
Capacité de dissémination	Les différents modèles utilisés pour prédire la progression de l'écureuil gris ont montré que qu'il était un très bon envahisseur. Les distances de dispersion lors de l'émigration des juvéniles ou des subadultes sont de l'ordre de 5 à 10 km, même lorsque les connections naturelles sont faibles (comme c'est le cas dans la plaine du Pô en Italie, par exemple). Ceci confirme une capacité de dispersion élevée chez cette espèce. De plus, en raison de l'attrait particulier qu'il génère, l'écureuil gris peut facilement traverser des barrières écologiques à cause de l'assistance de l'homme (translocation dans de nouveaux habitats).

EFFETS DE LA NATURALISATION

Impacts environnementaux	Il est probable que l'établissement de l'écureuil gris en Belgique et dans les pays avoisinants cause des problèmes pour la flore indigène, particulièrement en raison du comportement d'écorçage de cette espèce entraînant potentiellement des altérations écosystémiques. Par ailleurs, le problème d'exclusion compétitive que l'écureuil gris impose à l'écureuil roux est particulièrement inquiétant d'un point de vue de conservation de la nature. Pour la plus grande part des auteurs ayant traité de ce problème en Grande-Bretagne, l'écureuil gris conduit littéralement l'écureuil roux à l'extinction, non seulement en raison de la compétition qui survient entre ces espèces, mais surtout en raison du problème de transmission du poxvirus (SQPV) de l'espèce exotique à l'espèce indigène. Dans les zones où le virus est présent, le remplacement de l'écureuil roux est d'ailleurs beaucoup plus rapide qu'ailleurs, *S. carolinensis* y constituant le réservoir du virus. Enfin, des problèmes de compétition avec des oiseaux forestiers pourraient également survenir à des densités élevées en écureuil gris bien qu'aucune preuve formelle n'ait actuellement pu être apportée pour évaluer clairement ce risque.

GESTION DU RISQUE

L'écureuil gris est difficile à détecter lors des premiers stades d'une invasion, ce qui peut augmenter sa diffusion dans l'environnement. La voie d'entrée principale potentielle de l'espèce dans notre pays est liée à la fuite ou à la remise en liberté d'individus provenant de captivité. Les populations présentes les plus proches sont actuellement en Italie et en Angleterre, donc une expansion naturelle de celles-ci ne concernera pas notre pays, du moins dans un futur proche. Cela étant, vu l'ampleur du problème en Angleterre, la nécessité de mettre en place des stratégies de gestion à l'échelle de l'Europe s'avère prioritaire. Si l'espèce était détectée à l'état sauvage, il faudrait mettre urgemment en place des opérations d'éradication. Cependant, le premier principe de gestion à faire valoir est l'interdiction stricte d'importer l'écureuil gris, de le commercialiser et de le

détenir. Cette mesure efficace est nécessaire afin de réduire le risque d'entrée de l'espèce à un niveau acceptable.

En parallèle, comme pour les autres espèces d'écureuil, le renforcement des mesures de sécurité par rapport aux individus éventuellement captifs doit être mis en place (marquage et stérilisation), de même que l'obligation de renseigner rapidement toute fuite dans l'environnement. Cette condition doit précéder l'effort de détection et de contrôle des populations qui s'établiraient éventuellement. Pour la détection, en Angleterre, l'espèce étant répandue, elle fait partie d'une liste d'espèces pour lesquelles la collaboration pour le renseignement d'observations par le grand public est demandée. Comme pour les autres espèces d'écureuil mentionnées, afin de mener une éradication efficace en cas d'établissement, il est nécessaire de le faire le plus tôt possible et de sensibiliser au maximum le public et les collaborateurs potentiels. Le piégeage et le tir d'individus semblent donner des résultats intéressants aux premiers stades d'une invasion.

Samenvatting

WAARSCHIJNLIJKHEID VAN VESTIGING EN VERSPREIDING (BLOOTSTELLING)

Introductie in België	De kans bestaat dat de grijze eekhoorn op het Belgische grondgebied wordt geïntroduceerd doordat handelaars in huisdieren of particulieren de dieren onopzettelijk of opzettelijk uitzetten. Ook ontsnappingen uit particuliere kooien, huisdierenzaken en dierenparken vallen niet uit te sluiten. Omdat er zich geen in het wild levende populaties van *Sciurus carolinensis* in de omliggende landen (op het vasteland) voordoen, hoeven we via deze weg voor de komende jaren geen natuurlijke verspreiding van de soort te verwachten.
Vestigingsvermogen	In geval van introductie van grijze eekhoorn bestaat er een hoog risico dat zich in België en omliggende gebieden leefbare populaties zullen vestigen.De soort heeft een hoog invasief vermogen en vindt in bossen, bosbouwgebieden en parken in België geschikt habitat en voedsel. De Belgische ecoregio's hebben gepaste klimaatomstandigheden voor de soort. Bovendien is niet meer dan een handvol individuen nodig om succesvol een populatie te stichten.
Verspreidingsvermogen	De soort verspreidt zich zeer goed. De afstanden waarover grijze eekhoorn (onvolwassen en jongvolwassen dieren) zich verspreidt, variëren doorgaans van 5 tot 10 km. De gemiddelde snelheden van de lineaire ruimtelijke expansie op de Britse Eilanden en in het noorden van Italië bedragen respectievelijk 4-8 km/jaar en 17-18 km2/jaar. Door zijn hoge aaibaarheid kan de soort meer dan andere soorten met menselijke hulp ecologische barrières overbruggen (secundaire uitzettingen en translocaties naar nieuwe habitats).

EFFECTEN VAN VESTIGING

Milieu-impact	De kans is reëel dat vestiging van grijze eekhoorn in België en de omliggende landen problemen zal veroorzaken; deze soort eet in bosgebieden immers schors, wat tot economische verliezen in boomkwekerijen en bossen kan leiden. Grijze eekhoorns kunnen ook schade aan landbouwteelten zoals maïs aanrichten. Afgezien daarvan is het probleem van competitieve exclusie met de inheemse rode eekhoorn bijzonder onrustwekkend op het vlak van natuurbehoud. Volgens de meeste hiervoor aangehaalde auteurs leidt introductie van S. carolinensis in een gebied waar rode eekhoorn *S. vulgaris* voorkomt, tot het verdwijnen van deze laatste door competitieve uitsluiting en de overdracht van het poxvirus (SPQV) van de grijze op de rode eekhoorns. In gebieden waar het virus aanwezig is, wordt de rode eekhoorn veel sneller verdreven dan in andere gebieden omdat *S. carolinensis* een reservoir is voor dit virus. Hoewel daar geen sterke aanwijzingen voor bestaan, zouden hoge densiteiten aan grijze eekhoorn ook gevolgen kunnen hebben voor bepaalde bosvogels.

RISICOBEHEER

Het is weinig waarschijnlijk dat de grijze eekhoorn de komende jaren via natuurlijke expansie vanuit verwilderde populaties op de Britse Eilanden of het noorden van Italië België zal bereiken en er zich zal vestigen. Een grotere dreiging gaat uit van ontsnappingen of het uitzetten van dieren die in gevangenschap leven. Een strenger toezicht op het reeds bestaande verbod (Koninklijk Besluit) op het fokken, levend houden, vervoeren of verhandelen van de grijze eekhoorn ter bescherming van planten en plantaardige producten zou dan ook kunnen worden beschouwd als een efficiënte maatregel om het risico op introductie tot een aanvaardbaar niveau terug te brengen. Als overgangsmaatregel voor grijze eekhoorns die in gevangenschap leven, dient te worden teruggegrepen naar drastische beveiligingsmaatregelen, waaronder het oormerken en het systematische steriliseren, samen met een officieel toezichtsysteem en de onverwijlde meldplicht van ontsnapte exemplaren.

Deze preventieve maatregelen genieten de voorkeur boven een vroege detectie en populatiecontrole omdat zich na ontsnapping snel verwilderde populaties van grijze eekhoorn kunnen vestigen. Uitroeiingsacties zijn enkel in een pril stadium van de invasie een haalbare kaart en blijken bijzonder moeilijk te implementeren door de lage detectiekans bij lage densiteiten. Bovendien kan de soort zich, wanneer de gepaste ecologische omstandigheden aanwezig zijn, snel verspreiden vanaf de plaats van uitzetting en tonen ervaringen in het buitenland aan dat de publieke opinie zich vaak verzet tegen het afmaken van deze aaibare dieren.

STAGE 1: INITIATION

1.1 ORGANISM IDENTITY

Scientific name : *Sciurus carolinensis* Gmelin, 1788

Common names : (North American/Eastern) gray (or grey) squirrel (GB), grijze eekhorn (NL), Grauhörnchen (DE), Ecureuil gris (d'Amérique) (F).

Taxonomic position: Chordata (Phylum) > Mammalia (Class) > Rodentia (Order) > Sciuridae (Family).

Note: In the Sciurid family, within the Sciurini tribe, Wilson & Reeder (2005) consider 28 species in the genus *Sciurus : S. aberti, S. aestuans, S. alleni, S. anomalus, S. arizonensis, S. aureogaster, S. carolinensis, S. colliaei, S. deppei, S. flammifer, S. gilvigularis, S. granatensis, S. griseus, S. ignitus, S. igniventris, S. lis, S. nayaritensis, S. niger, S. oculatus, S. pucheranii, S. pyrrhinus, S. richmondi, S; sanborni, S. spadiceus, S. stramineus, S. variegatoides, S. vulgaris, S. yucatanensis.*

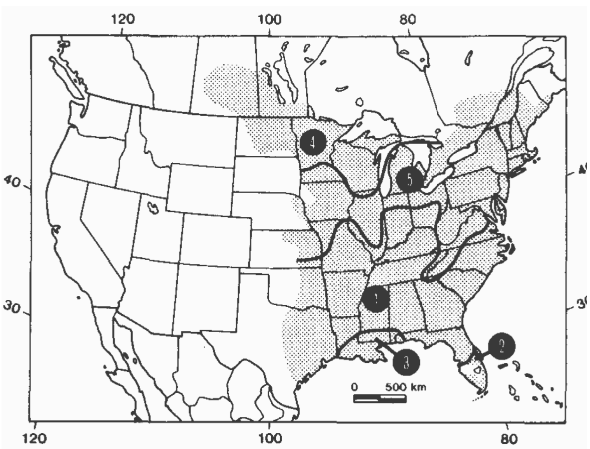
Among them, *Sciurus carolinensis*, which includes 5 subspecies, is native from North America but has been introduced in many countries like Britain, Ireland, Italy, Australia, South Africa and numerous localities in the West of North America. No particular information is available concerning the European subspecies (Chapuis & Marmet 2006). Because of its various English denominations, we will use the terms "gray squirrel" while talking about *Sciurus carolinensis*.

1.2 SHORT DESCRIPTION

The gray squirrel is a tree squirrel. An adult of *Sciurus carolinensis* weighs between 300-700 g (Koprowski, 1994; Flyger & Gates 1982). Its body-head length varies from 38 to 52,5 cm (Genovesi & Bertolino, 2006 (DAISIE) with a bushy tail from 15 to 25 cm. There is no sexual dimorphism in size or coloration. The gray squirrel looks a bit bigger and stockier than the red squirrel (*Sciurus vulgaris*) and is also more often seen on the ground than our native squirrel (MNHN 2012). With a white belly, the gray squirrel has mainly a pale gray fur, with usually some cinnamon tones. In the natural range, some individuals are melanic which has not been recorded in European areas of introduction. Some individuals can also be entirely white.

1.3 ORGANISM DISTRIBUTION

Native range



The native range of *Sciurus carolinensis* comprises the eastern United States (with a southern limit in eastern Texas and Florida). The range extends west to the edge of the deciduous forest and north to southern Canada (southern Quebec to Manitoba).

Fig 1. Distribution of the 5 subspecies of *S. carolinensis* in their native North American range (1=*S.c. carolinensis* Gmelin, 1788, 2=*S.c. extimus* Bangs, 1896, 3= *S.c. fuliginosus* Bachman, 1839, 4= *S.c. hypophaeus* Merriam, 1886, 5= *S.c. pennsylvanicus* Ord *in* Guthrie, 1815) (from Koprowsky 1994).

Introduced range

Belgium: The species is still not present in the wild in our country (Libois 2006, Branquart *et al*. 2009, Schockert 2010).

Rest of Europe: Different populations are established in the United Kingdom, Ireland and Italy (Fig.2).

Other continents: In the USA, introductions occurred in California, Montana, Oregon and Washington while in Canada, other introductions were done in Quebec, British Columbia, New Brunswick, Manitoba, Nova Scotia, Ontario (Barkalow & Shorten 1973, Flyger & Gates 1982, Teaford 1986, Koprowski 1994) and Saskatchewan (Nero 1958, Koprowski 1994).

Introductions also occurred in South Africa around the turn of the 19th-20th century and in Australia (1880) but, on this continent, the population was extirpated in 1973 (Seebeck 1984, Koprowski 1994).

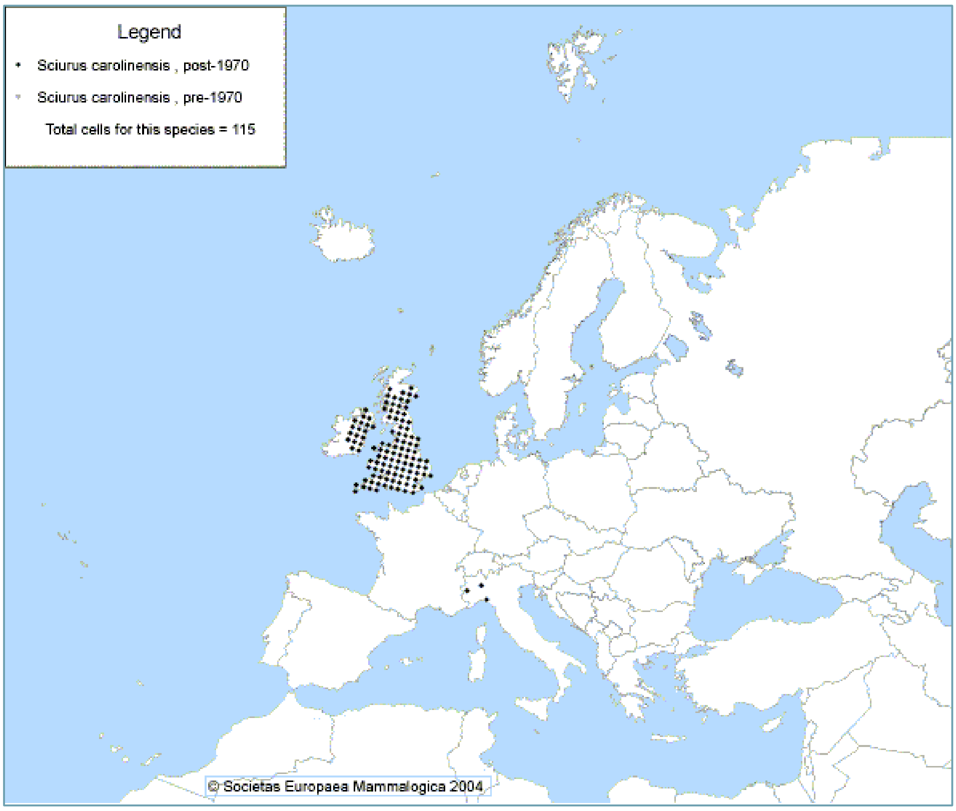


Fig 2. Introduction range of the gray squirrel *Sciurus carolinensis* in Europe (Societas Europea Mammalogica 2004)

1.4 REASONS FOR PERFORMING RISK ANALYSIS

Alien species introduction is considered as one of the most important threats to biodiversity (Lever 1994, Wilcove *et al.* 1998). The gray squirrel belongs to the category of the 100 most invasive species of the world (Lowe *et al.* 2000, Genovesi 2005). The main threat caused by its introduction in Europe is the extinction, in only some decades, of the European red squirrel (*Sciurus vulgaris)* in all areas of overlap with *Sciurus carolinensis* (Gurnell & Pepper 1993, Kenward 1983, Lurz et al 2001, Genovesi *et* *al.* 2009). It happened in England and Wales despite laborious efforts invested since the 1950s to limit its spread (ISSG 2005). The same situation also occurs in Italy (Wauters *et al.* 2007). *Sciurus carolinensis* has been described by many authors as more competitive than the red squirrel (Wauters *et al.* 2001, Bertolino & Genovesi 2003, Gurnell *et al.* 2004b, Bertolino 2008, Kumschick *et al.* 2011). Besides a better exploitation of deciduous woodlands (Gurnell 1987), the outcompetition is mainly due to transmission of a squirrel poxvirus which is almost always fatal to the red squirrel while the gray species is immune. Furthermore, gray squirrels seem able to establish viable populations in new habitats, with relatively few initial introduced individuals (Bertolino 2009, Lawton *et al.* 2010, CABI 2012). The ISEIA score of their potential risk to native biodiversity and environnement is of 11 (Branquart *et al*. 2009).

STAGE 2: RISK ASSESSMENT

2.1 PROBABILITY OF ESTABLISHMENT AND SPREAD (EXPOSURE)

2.1.1 Present status in Belgium

Until now, no information of presence of free-ranging gray squirrels is confirmed in Belgium. The species is thus considered as not established. Nevertheless, it could be obtainable in some pet market as documented for one pet shop of the Hainaut (Péruwelz) proposing for sale male and female gray squirrels bred in captivity via an Internet offer (www.2dehands.be, 22/10/2010).

2.1.2 Present status in neighbouring countries

The presence of the gray squirrel in Europe is documented since nearly one and a half century. The first introductions respectively started in 1876, 1911 and 1948 in the British Isles, Ireland and Italy (UNEP-WCMC 2010). In northern Italy, first gray squirrels were imported from England (ISSG 2005).
In Great Britain, introductions occurred from 1876 to 1929 in 30 sites of England and Wales and 3 sites in Scotland (Middleton 1931, Lloyd 1983, Gurnell 1987, ISSG 2005). From 1938, it was considered as illegal to import or keep the species in captivity (Ministry of agriculture 1937, Lever 1977, Newson *et al.* 2010). In Wales, England and Italy, introduced gray squirrels were brought from the U.S.A, and in Scotland, from Canada.

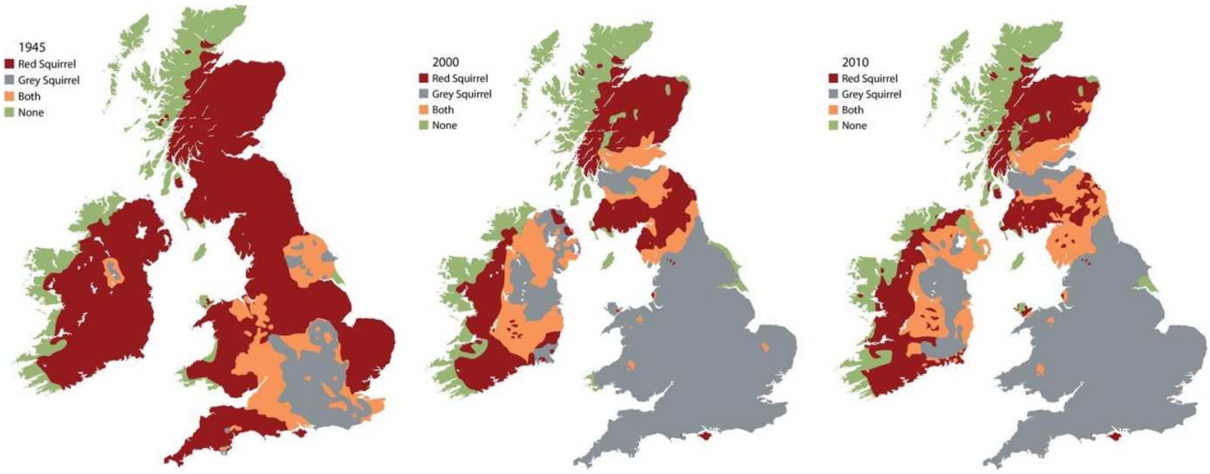
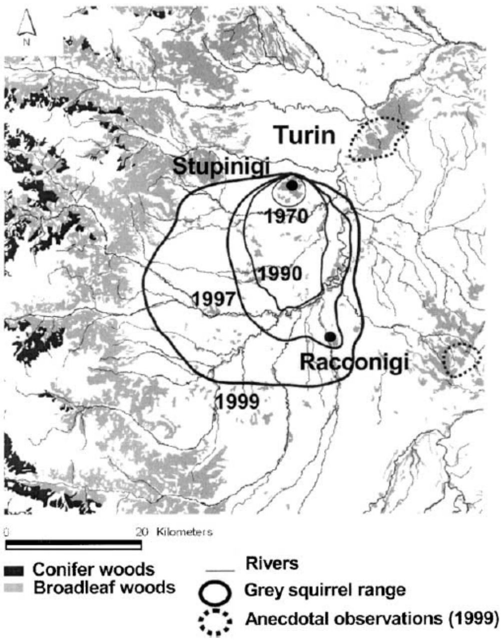


Fig. 3. Gray (*Sciurus carolinensis*) and red (*S. vulgaris*) distribution since 1945 in the United Kingdom (Red Squirrel Survival Trust 2010).

At first, the species did not spread far from the main locations of introduction but between 1930 and 1945, it rapidly expanded throughout Britain in number and range (Gurnell 1987, Mayle 2004). Then, it colonized a huge part of south-east and southern England, as well as the midlands and the Welsh borders and Yorkshire (Fig.3). It now occupies almost all of Wales and England and still progress northwards through northern England and west and southwards in Scotland (Pepper *et al.* 2001). In 1995, Harris *et al.* gave an estimation of the pre-breeding population of about 2.5 millions of gray squirrels for England, Scotland and Wales.

The Irish population originates from the introduction of six pairs of gray squirrels in 1913 in the County of Longford, for ornamental reason maybe followed by a second introduction in the same county in 1928 (O'Teangana *et al*. 2001). Gray squirrels are now widespread in central and eastern Republic of Ireland (EHS/NPWS 2007, Ross 2008). In 2007, they were present in 16 out of 26 counties (EHS/NPWS 2007). Currently, the spread is still in progress. However, gray squirrel populations of the United Kingdom and Ireland are "stuck" on islands which means the risk of entry on our territory is probably lower than as if the species was on the European continent. Therefore, the gray squirrel presence in Italy should be much trickier for European Nature Conservation in the future...

In northern Italy, gray squirrels were introduced in three locations: into Piedmont near Turin (Candiolo, Stupinigi forests; 2 pairs of individuals) in 1948, in Liguria (Genoa Nervi park; 5 animals) in 1966 (Currado *et al.* 1987, Wauters et al 1997) and in Trecate (Novara province; 3 pairs) in 1994 (Bertolino *et al.* 2000, Bertolino & Genovesi 2003). But according to the same authors, in this locality, the population nucleus was eradicated by trapping 2 years after introduction. but it could easily spread to Switzerland (Tattoni *et al.* 2006, Bertolino *et al.* 2008). In Liguria, the population remained localized along the coast with few possibilities of expansion in the hilly surroundings because of unsuitable habitats (Spano *et al*. 1999, Bertolino & Genovesi 2003, Venturini *et al* 2005).



The Piedmont population is the most worrying because of its huge spread since introduction. After a first phase of slow increase, *S. carolinensis* fastly extended its range in direction of the northern prealpine forests and the southern hazel plantations (Wauters *et al.* 1997b). In 1997, the species occupied around 380 km² of the high Po-plain (south and southwest of Turin) but it was expected to spread further.

Fig.4 Gray squirrel expansion in the 1970–1999 period. Distribution in 1970, 1990 and 1997 defined from observation data, distribution in 1999 defined on the basis of hairtube data (published in Bertolino & Genovesi 2003, from Wauters *et al*. 1997b).

Containment efforts were expected to limit the gray squirrel population, to prevent its expansion to France and Switzerland (Bertolino & Genovesi 2003) and to minimize the risk of significant damage to forests and the risk of red squirrel displacement in large areas of its range (Bruemmer *et al.* 2000, Lurz *et al.* 2001, Bertolino & Genovesi 2003, Genovesi & Bertolino 2006, Bertolino 2008). Containment attempts were started in 1997 but some radical animal rights organisations led legal actions to suspend the eradication campaign (Genovesi & Bertolino 2001, Bertolino & Genovesi 2003, UNEP-WCMC 2010). In the Piedmont population, despite the forested habitat fragmentation, a significant range expansion comprising continuous woodlands and residential parks followed this eradication actions break and the gray squirrel colonized new areas, reaching a range of 880 km² by the winter 1999-2000 (Bertolino & Genovesi 2003). More details about the dispersal capacity will be given in chapter 2.1.5.

Several population estimates based on models have been made. In 1997, Wauters *et al.* gave the number of 2500 *S. carolinensis* individuals in Italy which was implemented by Bertolino & Genovesi (2003) to 6400 individuals considering the differences in squirrel abundance among the woodlots.

2.1.3 Introduction in Belgium

There is currently no established wild population of gray squirrel in Belgium. Nevertheless, the great adaptability of the species and its high potential of colonization of forested habitats and urban parks have to be considered.

A review of *Sciurus carolinensis* in Europe was recently realized by the UNEP-WCMC (2010). The information collected about the trade of that species is the result of an Internet survey led between 4th-7th May 2010. It confirms that, for the specified period, gray squirrels were proposed for sale in Europe : in Denmark (1 offer; several individuals), in Italy (4 offers; several pairs and individuals), in Spain (3 offers; number of individuals unknown), in UK (1 offer; 0 individuals (currently sold out)) and in Austria (1 offer, number of individuals unknown). The price offers are around 150-200 € per animal. These advertisements didn't often mention the source of traded animals while some Internet offers ensured the animals were born in captivity.

Private persons in France, UK and Spain also used websites to request information on how to obtain gray squirrels. It also appeared that wild gray squirrels were caught and sold as meat in supermarkets and butcher shops (Schockert 2010). No specific information was found for Belgium during that survey (UNEP-WCMC 2010) but website offers were done in other conditions (see chapter 2.1.1). During the UNEP-WCMC survey, Finnish, Swedish and English websites were also selling squirrel skins or tails for fly-fishing, while a Swedish advertising was done for the use of make-up brushes made from gray squirrel hair. In conclusion, in 2010, the species was still traded in Europe as a pet as already affirmed by Genovesi & Bertolino in 2006.

Many squirrel species have been introduced worldwide for different purposes (Long 2003, Bertolino 2009). Currently, the most important pathway of introduction is linked to pet markets, private citizens and zoos. Because of such a trade, individuals of *S. carolinensis* are susceptible to be intentionally released (the most often) or to escape from captivity (only to a smaller extend) (Bertolino 2009).

ENTRY IN BELGIUM

It is likely that the gray squirrel could enter in Belgium through accidental or intentional release of animals coming from pet traders or private citizens. Escapes can also happen from private enclosures, pet shops and zoos. As no free-ranging population of *Sciurus carolinensis* occur in the neighbouring (continental) countries, a natural spread of the species is not expected through this pathway in the coming years.

2.1.4 Establishment capacity and endangered area

A/ Life-cycle and reproduction

Males are dominant on females and adults are dominant on juveniles. Most females reproduce at the age of 1,25 year old (Koprowski 1994, UNEP-WCMC 2010) but some of them can start breeding at 5.5 months old (Smith & Barkalow 1967). In the native range (Illinois), most breeding occurs according two peaks: the first one in December-February and a second one in May-June or a bit later in more northern latitudes (Koprowski 1994, Linzey *et al.* 2008, UNEP-WCMW 2010). A female may be followed by males for 5 days before oestrus and breed with several males. Gestation is of 44 days. An adult female could have one or two litter(s) per year, each made of 2 to 4 young squirrels (up to 8 in some cases). The first litter is produced between January and March (for 67% of the females, Lurz *et al.* 2001). A second litter may emerge in July or August (for 26% of the females, Lurz *et al.* 2001). The female nurses the offspring during 10 to 12 weeks (in spring for the first litter and/or in late summer-early fall for the second litter). Reproductive output, including the percentage of adults that produce young and the number of litters per year, is positively correlated with mast abundance. The maximum longevity is about ten years but the mean average life expectancy is of 7 to 9 years.

The gray squirrel is active during the day and rest at night in its nest.The pattern of activity looks rather like the one of *Sciurus vulgaris* with a bimodal activity rythm (2 hours after the sunrise and 2 to 5 hours before the sunset) from spring to fall. During the winter season, the activity appears as unimodal and the activity is reduced to less than 35% of the daylight (which reaches 70% during the good season). Females may be more active than males in spring and summer, which can be the contrary in winter (Flyger & Gates 1982, Koprowski 1994). If the weather is really harsh and cold (much snow, heavy rain, strong wind), gray squirrels may stay in their nest and remain inactive for one or two days.

B/ Climatic requirements[2]

A climate matching is required to enable a population establishment from the native range to a new area of introduction. When the latitudinal distance between these areas enlarges, the likelihood of success in the recipient area is normally lower (Duncan *et al.* 2001, Forsyth *et al.* 2004).

According to the closeness between Belgian and native range latitudes, we may suppose a good convenience with the climatic requirements of *Sciurus carolinensis* if introduced. Furthermore, since other introductions in western Europe were successful and led to gray squirrel population establishments, and since suitable forested habitats for that species are widely represented in Belgium, we assess the risk of establishment as being likely if *Sciurus carolinensis* is introduced.

[2] Organism's capacity to establish a self-sustaining population under Atlantic temperate conditions (Cfb Köppen-Geiger climate type) should be considered, with a focus on its potential to survive cold periods during the wintertime (e.g. plant hardiness) and to reproduce taking into account the limited amount of heat available during the summertime.

Naturally occurring in temperate habitats and considering the winters are even harsher in some parts of its natural range (Koprowski 1994), the gray squirrel has found perfect conditions to subsist easily in Europe (Gurnell 1987).

C/ Habitat preferences[3]

In its native range, the gray squirrel likes large areas of mature continuous hardwoods (> 40ha), and especially oak, oak-hickory, beech-maple forests because they produce winter-storable seeds (Gurnell 1987, Koprowski 1991, 1994, Bruemmer *et al.* 2000). The diversity of nut trees is therefore appreciated. But it is also extremely adaptable and can use urban and suburban parks and gardens as well as mixed-conifer forests and floodplains. The presence of open waters is usefull and narrow bands of hardwoods along streams are important habitats for the species, facilitating movements between forest patches (Fischer & Holler 1991). Old deciduous forests belong to gray squirrel favorite habitats because of the food supply (nuts) they can find in such environment. The densities of *S. carolinensis* are also linked to the abundance and diversity of food availability (Linzey *et al.* 2008).

Tree cavities are also more abundant in old forests and gray squirrels will use them as shelters even if they can also build their own nests with leaves (height *of* ± 8m). Good tree cavities are used for nesting, especially during the winter-spring period (Teaford 1986).

In introduced areas, the gray squirrel uses different kinds of habitats :

- in South Africa, in the Western Cape, it mainly uses pine and oak forests;
- in Europe, broadleaf forests and to some extent conifer woodlands, poplar plantations and parks are the main habitat types used by gray squirrels. But they also take profit of maize fields and orchards as suitable habitats for food supply (Gurnell 1987, Wauters *et al.* 1997a, b, Bertolino *et al.* 2008). However, it could be possible that coniferous woods may constitute a refuge for red squirrels in case of uncontroled expansion of *S. carolinensis* (Kenward *et al.* 1998).

In strongly fragmented habitats, the distribution of gray squirrels is influenced by the size of forest patches and habitat quality variables (Wauters *et al* 1997b). For example, in the Po-plain, 85% of the woodlots of at least 1ha (large enough to contain home ranges of several individuals) adjacent to poplar plantations and in which there were at least 3 species of large seed producing trees (high habitat quality) were occupied by gray squirrels. In England, Fitzgibbon (1993) pointed out the importance of hedgerow density and large wood patches (> 5ha) proximity: they were positively influencing the gray squirrel presence. However, in the Po-plain, isolation factors did not affect its presence (Wauters *et al.* 1997b) while red squirrels were dependent of large wood proximity along rivers (Celada *et al.* 1994).

D/ Food habits[4]

[3] Including host plant, soil conditions and other abiotic factors where appropriate.

[4] For animal species only.

The gray squirrel is omnivorous in its native range as well as in areas of introduction. It is able to consume many different items although some are dominant. Its diet comprises seeds (hazelnuts, nuts, acorns, beechmast), fruits, berries, fungi, buds, coniferous seeds, tree sap, and sometimes some insects, bird eggs and chicks and amphibians (Flyger & Gates 1982, Gurnell 1987, Koprowski 1994, Genovesi & Bertolino 2006, Linzer *et al.* 2008).

However, all year long, large seeds of deciduous trees constitute the main food supply for *S. carolinensis* (Moller 1983, Gurnell 1987, Wauters *et al.* 1997a). In England, for example, gray squirrels were more likely to occur in woodpatches including oak, beech and hazel because they offer the preferred gray squirrel food (Fitzgibbon, 1993). When the food supplies are scarce, gray squirrels strip bark to access the bast and cambian layers of the trees. In Italy it mainly appeared in poplar plantations, sometimes causing huge damage to timber and consequent economic losses. This theme will be discussed further (chapter 2.2.2.A).

As the red squirrel, it is also a scatterhoarder species hiding seeds (like acorns and nuts) during fall to face winter and spring shortage (Linzey *et al.* 2008). In autumn, *S. carolinensis* buries seeds in pits of 2 cm depth to keep them for later consumption. Gray squirrels have an excellent spatial memory allowing them to relocate these caches. They sometimes pilfer the caches of conspecifics or red squirrels (CABI 2012). For *S. carolinensis*, habitat quality is highly dependent of food availability (Lurz *et al.* 2001).

E/ Control agents

The gray squirrel has many predators but, according to Teaford (1986), it does not limit its populations. However, in its North American native range, snakes (*Crotalus horridus*, *C. adamanteus, Elaphe obsoleta*), raptors (*Buteo jamaicensis, B. lineatus, Accipiter gentilis, A. cooperii, Bubo virginianus, Strix varia*), mustelids (*Mustela frenata, M. vison*), red and gray foxes (*Vulpes vulpes, Urocyon cinereoargenteus*), bobcat (*Lynx rufus*), wolf (*Canis lupus*), coyote (*C. latrans*) and domestic cats and dogs are the main predators of *Sciurus carolinensis* (Flyger & Gates 1982, Koprowski 1994, Chapuis & Marmet 2006). In Europe, the red fox and domestic animals like cats and dogs have been considered has the most important predators (Chapuis & Marmet 2006) but some raptors could also prey on gray squirrels. Fatal falls are rare but possible (Koprowski 1994).

In the native range, numerous parasites have been found by Davidson (1976) and Flyger & Gates (1982, cited in Koprowski 1994) : 6 protozoans, 2 trematodes, 10 cestodes, 1 acanthacephalan, 23 nematodes, 37 mites and ticks, 7 lice, 17 fleas, 1 dipteran, the bot fly (*Cuterebra emasculator*). The mange mite can cause *S. carolinensis* death.

Other known pathogens are : California encephalitis virus, poxvirus, induced fibromas of the skin, human echovirus 1/8 complex, cariosarcoma mammary tumors, acute fatal toxoplasmosis, tularemia, tetanus, leptosirosis, Q fever and rarely rabies, yersinosis, ringworms. Systemic phycomycosis may cause death.

The availability of tree seeds plays on the reproduction, mortality and space use variables (Gurnell 1987, Lurz *et al.* 1995, Wauters & Lens 1995). The food richness is defined by the area and structure of suitable woodland. Survival and breeding activity decrease during years of poor seed production and increase in good years (Koprowski 1991). Kenward & Holm (1993) have also pointed out the positive correlation existing between the gray squirrel density and breeding success with the abundance of hazelnuts and acorns.

In the native range, mean annual mortality reported for adults is between 42 and 57% (Koprowski 1994). In Italy, for the development of a predictive model of dispersion based on historical data, and under average conditions, the annual mortality rate estimate for adults was around 40%, while the juvenile mortality rate reached 75% (Lurz *et al.* 2001). These records are the mean values of mortalities found in different studies[5].

F/ Establishment capacity in Belgium

A logistic regression analysis performed by Bertolino (2009) pointed out that, generally, squirrel establishments into new areas are less likely to take place when the distance from the native range along a gradient of latitude increases, and they are more likely to happen when the number of released animals augments. For *Sciurus carolinensis* (and other squirrel species), the number of introduction events is also correlated to the capacity of establishment.

The spread of an exotic species is facilitated by some main factors such as an appropriate climate, a good food supply, a suitable habitat and conveniences for dispersal (Lever 1994): as documented above, these requirements are widely encountered in Belgium. A settlement could even be fast and straightforward considering the competitive exclusion driving the red squirrel to extinction in the United Kingdom and in Italy.The likelihood that one pair of *Sciurus* species released in the wild would establish a new free-ranging population is higher than 50% (Bertolino 2009). The establishment likelihood increases proportionally to the number of individuals released.

G/ Endangered areas in Belgium

All the wooded areas found in Belgium consist in an optimal habitat for the development of the gray squirrel, where it could form dense populations. Urban parks and other small patches of wooded habitats may also be interesting for this squirrel which can be really adaptive. Thus, except the maritime region of Belgium, it seems the gray squirrel could occur nearly in any region where interesting woodlots are present.

[5] For adult mortality, rates of 20 to 60%, for juvenile mortality, rates of 40-80% (data found in Gurnell 1983, 1987; Koprowski 1991, 1994)

Establishment capacity in the Belgian geographic districts:

Districts in Belgium	Environmental conditions for species establishment[6]
Maritime	Inadequate
Flandrian	Optimal
Brabant	Optimal
Kempen	Optimal
Meuse	Optimal
Ardenne	Optimal
Lorraine	Optimal

ESTABLISHMENT CAPACITY AND ENDANGERED AREAS IN BELGIUM

If an introduction of *Sciurus carolinensis* occurs, the risk of establishment of a self-sustaining population in Belgium and neighbouring areas is high because the gray squirrel has a high invasive ability and will find, in Belgium and in the Ecoregion, suitable climatic conditions, habitats and food disponibility in forests, woodlots and parks. Furthermore, only a few individuals are needed to develop a founding population.

2.1.5 Dispersion capacity

A/ Natural spread

The main dispersal movements among gray squirrel populations occur in fall and spring, when population saturation increases hostility between individuals (Koprowski 1994, Bertolino *et al.* 2008). These are mainly juveniles and subadults that disperse. Adults usually move within their home range but they may also move further, especially in case of food shortage. Juveniles and subadults (close to sexual maturity), in quest of a free home range, usually diffuse within a distance of a few kilometers from the natal area and males are supposed to disperse a bit further and more often than females (Koprowski 1994, Chapuis & Marmet 2006). The longest recorded movement made by a gray squirrel is about 100 km but most of the juveniles and sub-adults do not disperse further than 10 to 20 km (Sharp 1959 *in* Koprowski 1994). However, the juvenile dispersal is linked to a high mortality (Koprowski 1994). Large scale one-way emigrations have been observed when the population density is high and/or the seed production is scarce (Linzey *et al.* 2010).

Home range averages 0.5-10 (or even 20) ha, but most of the time, they don't exceed 5 ha (Teaford 1986, Koprowski 1994). They are generally larger during the breeding season, especially for males. Male home ranges are usually 1.2 times bigger than those of females (Chapuis & Marmet 2006). Higher is the population density, smaller are individual home ranges. Overlaps are common between

[6] For each district, choose one of the following options : optimal, suboptimal or inadequate.

individuals (except in the core area of individual home ranges). The territoriality is not established but during juvenile emigration, agonistic behaviors are more important.

Population densities vary according forest types (Koprowski 1994) and thus, food richness. In continuous woodlands, gray squirrels average less than 3 individuals/ha (Barkalow *et al.* 1970) while they may reach 16 individuals/ha in woodlots of maximum 10 ha. In urban parks they may even reach higher densities (21 gray squirrels/ha).

It is possible to predict the spatial spread of a species by using models but then it is useful to compare simulation results to the field dynamics observed (Ball *et al*. 2003). Lurz *et al.* (2001) developed a model for gray squirrel spread from the Italian population of Piedmont. Based on historical data (Thompson 1978, Koprowski 1994), Lurz *et al.* considered the dispersal as a process occurring once a year and mainly for subadults and juveniles and estimated the maximal individual dispersal distance of 5 km. Koprowski (1994) defined a dispersal distance of a few kilometers but also noticed some individuals may spread beyond a distance of 10 km. If no suitable habitat was found and available within that distance, dispersers were supposed to die (in the model). This value of 5 km was defined on the basis of dispersal distances published by Thompson (1978), Koprowski (1994) and according personal observation of Wauters (Lurz *et al.* 2001): the average distance was comprised between 1 and 5 km. In 2003, Bertolino & Genovesi analyzed gray squirrel population spread in Italy thanks to field data collected since the introduction of population founders. They assumed that the species spread in Piedmont took place in two phases. The first phase showed a slow increase and then was followed by a second quick phase of expansion during the period 1998-2000. This evolution appears in table 1. Based on these results, the population growth was predicted to be exponential (Fig.3).

Period	Number of years	Range by the end of the period (km^2)	Range increase during the period (km^2)	Mean annual colonised area (km^2/year)
1948–1970	22	25	25	1.1
1971–1990	20	243	218	10.9
1991–1997	7	380	137	19.6
1998–1999	2	880	500	250
Total	51	880	880	17.2

Table 1. Bertolino & Genovesi 2003 : area colonised by the gray squirrel in Piedmont from its introduction since 1999

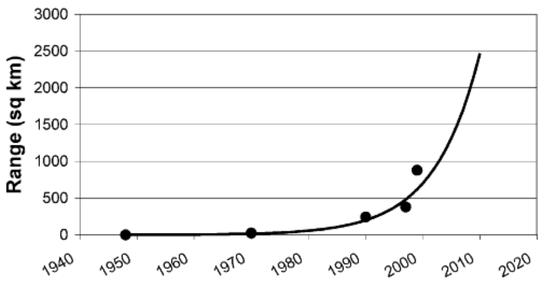


Fig 5. Exponential growth model (from introduction until 2010 applied to gray squirrel range data (black dots). Bertolino & Genovesi 2003.

Bertolino *et al.*(2008) developed a new model for the potential spread of *Sciurus carolinensis* in Italy and conceived two scenarios : one considering the dispersal distance of 5 km chosen by Lurz *et al.* (2001), a second one taking into account a dispersal distance until 10 km (Tattoni *et al.* 2004), to consider uncertainties about dispersal distances.

According to data analyzes, the progression of *Sciurus carolinensis* in Italy is high, with an annual dispersion of 17.3 km^2 (Bertolino *et al.* 2008, Bertolino 2009) which is close to the value of 18 km^2/year reported by Okubo *et al*. (1989) for Great Britain. The spread of *S. carolinensis* range was predicted to increase, with a high probability to reach Switzerland and France within the next few decades (around 2048 or a bit faster according, see Fig.6.).

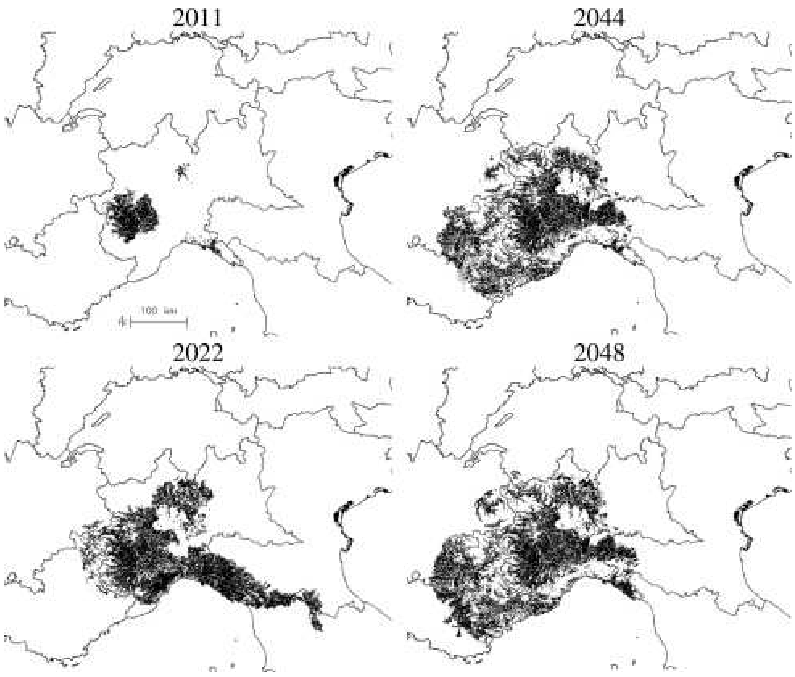


Fig.6. Simulation of the dispersal of *Sciurus carolinensis* in Italy in the worst case scenario with only good and mast year seed crops and considering a maximum dispersal distance of 10 km (in black: >80% probability of colonising, in gray: 50–80% of probability) (Bertolino *et al*. 2008).

In the United Kingdom, dispersal distance and range expansion have also been used for a gray squirrel spread model. Rushton *et al.* (2000), lacking of accurate estimates of dispersal for *S. carolinensis* introduced populations, considered a spread distance of 5 km because gray squirrels had been recorded in two concomitant 5-km national grid reference squares (Norfolk) during successive years up to 1967.

As for the red squirrel, the connectivity potential for *S. carolinensis* could increase with the use of cables, bushes, isolated trees, hedgerows and high vegetation as scrubs along open fields and rivers (Fitzgibbon 1993, van Apeldoorn *et al.* 1994, Wauters *et al.* 1994). Tattoni *et al.* (2004) also demonstrated that each gray squirrel population has its own dynamics influencing the dispersal process. In both native and introduced ranges, the gray squirrel uses forested bands along rivers as dispersal corridors (Currado, pers.obs *in* Wauters et al 1997). The high habitats fragmentation (like in the Po-plain area) may also affect the gray squirrels dispersal in a way that they emigrate to settle in other forested areas only when the good woodpatches are saturated.

B/ Human assistance

According to Bertolino & Lurz (2011), *Sciurus carolinensis* exemplifies our complex relationship with introduced non-native species colonizing not just remote woodlands and forests, but often starting their invasion from urban or suburban gardens or parks, as the result of human introductions. Trade offers found in the Internet survey led in 2010 by the UNEP-WCMC also demonstrate that private people can easily find individuals of *S. carolinensis* in different European countries (pets shops, private citizens, etc.). Therefore, the risk of potential invasion by escape or release is especially worrying as the species is already established in different European countries (Bertolino 2009). The recklessness of authorities could also be problematic, like in the Novara Province where the municipality of Trecate released 3 couples of gray squirrel in a public park for ornamental reasons in 1994 (Bertolino & Genovesi, 2003). Fortunately, they were removed two years later.

The strong appeal of squirrels to humans makes the situation even more complex to manage because it may lead to additional introductions by translocation of individuals from a source population of a country to new areas, helping the species to overcome ecological barriers and thus, increasing its distribution (Bertolino & Lurz 2011).

According to Bertolino (2009), identifying the main pathways of introduction of invasive species is essential to reduce the risk of new introductions and is more helpful than targeting independently on species. Indeed one pathway can be used by different species (Wittenberg & Cock 2001, Christy *et al.* 2007). The first cause of mammal introductions in Europe is their release while the second is their escape (Genovesi *et al.* 2008; Hulme *et al.* 2008). Therefore, human activities are strong causes of mammal invasions and the way the recipient human societies will consider the new species may also potentially affect the invasion rate of that species (Hulme *et al.* 2008).

DISPERSAL CAPACITY

The different models used to predict *Sciurus carolinensis* spread have shown it is a very good invader. Dispersal distances during emigration (subadults and juveniles) are of 5-10 km, even when natural connexions are weak (like in the Italian Po-plain). Thus, the gray squirrel has a high dispersal ability. Moreover, because of its strong appeal to humans, and more than many other species, it can cross ecological barriers with some human assistance (translocation into new habitats).

2.2 EFFECTS OF ESTABLISHMENT

Within a bit more than a century, establishment effects of the gray squirrel in the United Kindgom, Ireland, and more recently, in Italy, have been widely documented.

Sciurus carolinensis impacts on biodiversity: directly through predation (on birds, Newson *et al.* 2009) and competition (with the red squirrel) but also indirectly through changes to forest composition and connected fauna (despite all the impacts have not been accurately estimated) (Mayle 2004). The continuous displacement of red squirrels in areas of connection between both *Sciurus* species remains a serious problem (UNEP-WCMC 2010). Economic losses due to bark stripping are also pointed out even if the presence of *Sciurus carolinensis* could be beneficial to woodland biodiversity by increasing the amount of deadwood (Mayle 2004).

2.2.1 Environmental impacts

A/ Competition

Introduced many times into some European countries, the gray squirrel drove the native European red squirrel to extinction in areas of overlap mainly because of the competitive exclusion principle (Bertolino 2009). The range of *Sciurus carolinensis* is still progressing in the British Isles, Ireland and Italy, causing a continuous displacement of *Sciurus vulgaris* (Kenward & Holm 1993, Rushton *et al.* 2000, Bruemmer *et al.* 2000; Lurz *et al.* 2001, O'Teangana *et al.* 2001, Bertolino & Genovesi 2003, Genovesi & Bertolino 2006, Bertolino *et al.* 2008, Ross 2008, UNEP-WPMC 2010). It has been clear that the red squirrel population decline in UK and Italy was linked to the gray squirrel spread but the mechanism of replacement remained vague for a long time (Skelcher 1997, Rushton *et al.* 2000). In Italy, the replacement of *S. vulgaris* by *S. carolinensis* showed a reduction of the red squirrel's range of 46 % from 1970 to 1990 followed by a decrease of 55 % from 1990 to 1996 (Wauters *et al.* 1997a, Bertolino & Genovesi 2003). Hypothesis of competition for food or/and for space between young individuals of both species during settlement attempts, in a common area, were verified (Wauters & Gurnell 1999, Rushton *et al.* 2000).

Since the gray squirrel expanded its range in the UK in the 1930s, the species colonized a big part of England, Wales, and the Scottish lowlands (Gurnell & Pepper 1993) and progressively replaced the European red squirrel (Gurnell 1994, Bruemmer *et al.* 2000, Tompkins *et al.* 2002, UNEP-WCMC 2010). By the end of the 20th century, the red squirrel became extinct in southern England, except in some islands such as the Isle of Wight (Bruemmer *et al*. 1999). A few isolated populations could still be found in central England and parts of Wales. In northern England and Scotland remained the bastions of the red squirrel population in UK (see Fig.3.).

Only the north of England and a few southerly areas still count red squirrel populations. The presence of coniferous forests seems to be the main reason of non establishment of *S. carolinensis* in most of these areas. There, it can not easily outcompete the European squirrel. In other *Sciurus vulgaris* preserved areas, the gray squirrel has been actively fought to prevent its establishment. However, the red squirrel population decline is still relevant today despite ongoing control efforts made since the 1950s by the British government, especially in northern England (Kenward & Parish 1986, Gurnell & Lurz 1997, Lurz *et al.* 1998, Bruemmer *et al*. 2000, Mayle *et al.* 2007, Signorile & Evans 2007). The gray squirrel has spread to almost all of England and Wales where its estimated population reaches 2.5 millions of individuals (Harris *et al*. 1995).

The red squirrel replacement also occurred in Italy with the fast expansion of *S. carolinensis* near Turin and Genoa in 1946 and 1966 (Gurnell and Pepper 1993, Wauters *et al.* 1997, 2001). The same situation was reported in Ireland (Reilly 1997). In that country, the red squirrel still remains widespread and locally abundant, except in two counties (Meath and Westmeath, north of Dublin) where *S. vulgaris* population decrease was concomitant with its longest co-existence with the gray squirrel (O'Teangana *et al.* 2001, UNEP-WCMC 2010).

Several characteristics of the gray squirrel have contributed to the replacement of the native red squirrel in many areas, preventing their co-existence in a same habitat (Paling 2008). The mechanism of interspecific competitive exclusion is not fully understood (UNEP-WCMC 2010) but shows an overlap of activity patterns, space use and food supply utilization between both species in almost every stage of life (Wauters *et al.* 2002, Gurnell *et al.* 2004a, Bertolino 2008). *S. carolinensis* also digests acorns more efficiently than the red squirrel does (Bertolino 2008). Because of food competition, Wauters *et al.* (2005a) have pointed out different factors affecting the red squirrel: decrease of body growth, reproductive success and recruitment rate (enhanced by the juvenile emigration). Another important factor of interspecific competition, known as pathogen-mediated competition (Gurnell *et al.* 2006) is the better resistance of *S. carolinensis* to the squirrel poxvirus[7] while this virus has, most of the time, a lethal effect on red squirrels (Kenward & Holm 1993, Rushton *et al.* 2000, Bruemmer *et al.* 2000, O'Teangana *et al.* 2001, Bryce *et al.* 2001, Tompkins *et al.* 2002, Gurnell *et al.* 2004, EHS/NPWS 2007, Bertolino *et al.* 2008, Paling 2008). The threat of *S. carolinensis* continuous spread on the red squirrel populations has been reported many times, especially regarding its potential development in Europe from Italy (Shar *et al.* 2008, Bertolino 2009, UNEP-WCMC 2010, Bertolino & Lurz 2011).

The gray squirrel could also potentially compete with woodland birds for nest sites and food (Hewson and Fuller 2003) and with the common dormouse* (*Muscardinus avellanarius*) for food access (Gurnell & Mayle 2003; Hewson *et al.* 2004, ISSG 2005).

B/ Predation

According to Mayle & Smith (ISSG 2005), gray squirrels predate nests of a wide range of bird species both in North America and Europe. Species most at risk are those with open nests in the canopy, although birds nesting on the ground and in the understorey are also vulnerable.

In the introduced European range of *S. carolinensis*, different publications defined it as a bird predator for chicks and eggs (Moller 1983, Hewson & Fuller 2003, UNEP WCMC 2010). During the last fourty years, while *S. carolinensis* abundance in UK was increasing, woodland birds seem to have markedly declined (Hewson & Fuller 2003) and are now on red or amber list of 'Birds of Conservation Concern' in the UK (Gregory *et al.* 2002). On the other hand, gray squirrels are known to prey on nests of numerous bird species (Moller 1983, Hewson & Fuller 2003). Now absent from a large part of the United Kingdom, *Sciurus vulgaris* has also been considered as a bird predator before it became extinct in many areas, but it occurred at lower densities than the gray squirrel (Macdonald & Barrett 1993, Newson *et al.* 2010) and could therefore be historically associated to a lesser impact.

However, recently, Newson *et al.* (2010) compared extensive national bird and gray squirrel monitoring data in England. They checked positive and negative associations between squirrels and birds: they found little evidence that increases in *S. carolinensis* abundance (during the period 1995-

[7] The squirrel poxvirus will be further discussed (chapter 2.2.1.E.)

2005) had driven observed declines of the 38 woodland bird species[8] screened in their analysis. They also noted that their results concurred with results of the Repeat Woodland Bird Survey (Amar *et al.* 2006) concerning the population changes of woodland birds since the 1980s (data of the British Trust for Ornithology/JNCC/RSPB Breeding Bird Survey 1995-2005). Their study enlightened that squirrel numbers were significantly higher in sites with hawfinch* (*Coccothraustes coccothraustes*) and lesser spotted woodpecker* (*Dendrocopos minor*) declines, but the data were insufficient to detect any correlation. Langston *et al.* (2002) already suggested the hawfinch vulnerability to *S. carolinensis* predation. However, Amar *et al.* (2006) mainly attributed these bird declines to the woodland structure changes (in wintering grounds especially).

For Newson *et al.* (2010), the common blackbird (*Turdus merula*) and the Eurasian collared dove (*Streptopelia decaocto*) were, for instance, undergoing more nest failure at the egg stage when the gray squirrel abundance was high, suggesting a predation during that phase. Nevertheless, this bird species abundance did not decrease during the study period. In addition, the Eurasian Jay (*Garrulus glandarius*) was presenting the highest decrease in growth rate as squirrel abundance increased, with an estimated decline of 1.7 % in growth rate for each gray squirrel recorded (Newson *et al.* 2010).

Finally, Newson *et al.* (2010) could not exclude that some bird species populations had been depressed in particular sites where gray squirrels were abundant, but they mainly explained these facts by the habitat quality variability.

In south Africa, the gray squirrel is not seen as a serious threat to local biodiversity despite it can eat eggs and chicks (Hamerton 2012) but detailed information are absent.

S. carolinensis often co-occurs with fox squirrels (*S. niger)* in its native range but the competition seems weak because gray squirrels prefer dense mature hardwood forests with significant undergrowth contrary to fox squirrels inhabiting open woodlands with sparse undergrowth (Steele & Koprowski 2001).

C/ Herbivory

According to the UNEP-WCMC review (2010), *S. carolinensis* was broadly accused to cause considerable damage to woodland and timber plantations (like poplar plantations in northern Italy, Wauters *et al.* 1997) through bark-stripping (Kenward and Holm 1993, Bruemmer *et al.* 2000; Lurz *et al.* 2001; Bertolino and Genovesi 2003; ISSG 2005, IUCN 2005, Bertolino 2008, Bertolino 2011). The gray squirrel removes bark from trees, particularly in hardwood forests (oak, sycomore and beech, principally) which results in wounds that severly degrade timber quality, causing significant economic losses (Dagnall *et al.* 1998, Lurz *et al.* 2001, Currado *et al.* 1987). However, reasons for such a behaviour remain unclear (Lawton *et al.* 2010). Squirrels strip the outer bark of trees, particularly from late spring (late April) to July (see Fig.5).

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[8] including 27 open-nesting species whose nests may be vulnerable to predation by grey squirrels, and 11 hole-nesting species whose eggs and nestlings should generally be afforded greater protection from grey squirrel predation (in order to compare the results for these two categories).

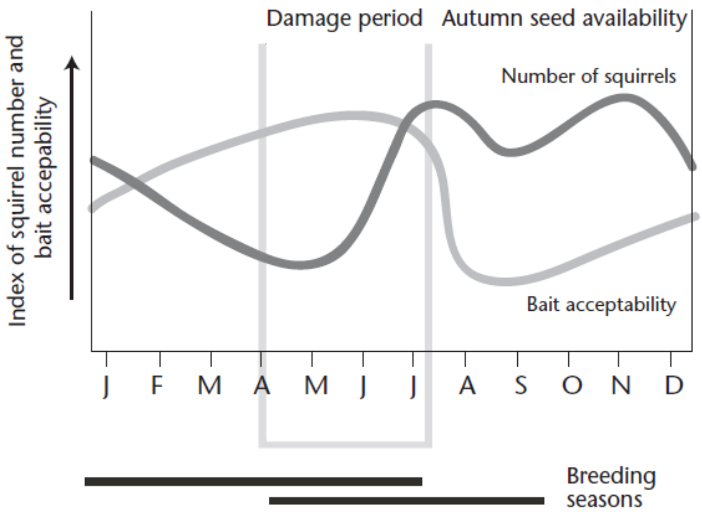

Fig. 5. Relationship between gray squirrel density, breeding success, food availability and bait acceptability

The main effects of bark stripping have been summarized by Bruemmer (2000) and Mayle (2004):

- bark damage location on trees may varies according the tree species: some are probably easier to strip according the bark thickness;
- the wounds may degrade the timber and cause an irregular growth of wood or stain/deterioration of wood because of permeation of infectious agents;
- stems can be deformed and if the main one is attacked, a fork is developping, diminishing future economic returns;
- a growth rate reduction can affect the trees because of the damage caused or the canopy disappearance;
- different kinds of "wounds" are registered :
  - basal damage (within 1m of the ground) is the most common in beech (*Fagus sylvatica*);
  - crown damage mainly occurs in the canopy of oaks and different conifers;
  - stem damage, between 1m high and the tree crown, mainly concerns sycamore, beech, birch, larch and lodgepole pine. Wounds at that level often harshly impact timber quality.
- basal and stem damages generally accumulate with years but old wounds often become callous, hiding the damage until tree cut.
- finally, the tree may die if completely ring-barked or if pathogen agents (rotting or staining fungi) can occur the site of wounds (Dagnall *et al.* 1998). This kind of wound can be serious enough to kill most of the young trees in a specific site (Shorten 1957, Kenward *et al.* 1992). Ring-barked trees may snap the weakened trunk in case of violent winds (especially for oak, poplar, Scots pine and Norway spruce), sometimes causing the total loss of timber if the break occurs at a low level.

The barkstripping does not occur because of hunger or thirst, according to Kenward (1983). Of course, even if squirrels eat some of the inner bark when soft (Mayle, 2004). Meanwhile, damage levels increase with the density of gray squirrels, especially with large numbers of juveniles entering the population in summer (Kenward 1983, Kenward & Parish 1986, Forestry Commission 2012). If numerous, the squirrels also have more contacts among themselves, including agonistic behaviours. This may lead to the displacement of young individuals in other areas where bark stripping may increase. At least, when gray squirrel densities reach 4 to 5 individuals per hectare (which is considered as a rather low density), bark attacks are triggered (Forestry Commission 2012).

In the UK, gray squirrel barkstripping affects many broadleaf tree species and cause important economic losses (Rowe & Gill 1985, Gurnell & Pepper 1988, Kenward 1989, Kenward *et al.* 1992, Mayle 2004). In Italy, stems of popular trees are particularly susceptible. Therefore, they may girdle so that the top dies and is blown down by tough winds (Currado *et al.* 1987, Bruemmer et al 2000).

Rowe & Gill (1985) already identified 40 species of broadleaved and coniferous trees undergoing such damage and pointed out regional differences in frequency of attacks among these species. Trees presenting a thin bark (oak, sycamore, beech, sweet chestnut, pine, larch and Norway spruce), aged of 10-40 years and presenting a fast growth (and a good sap flow) are more sensitive (see table 2, Mayle 2004).

Species	Survey year			
	1954	1955	1984	2000
Beech	46	51	87	66
Sycamore	70	43	85	100
Oak	21	14	41	40
Scots pine	6	2		16
Larch	7	4		8
Lodgepole pine	N/A	N/A		33
Sweet chestnut	9	4		33
Norway spruce	N/A	N/A		16
Ash	10	16	36	33
Birch	15	12	9	
Sitka spruce	N/A	N/A		0
Poplar	3	0	29	

Table 2. Relative frequency of damage by gray squirrels revealed in Forestry Commission surveys (Mayle 2004).

Provided that trees are big enough to support a squirrel weight, they can be barkstripped (Mayle 2004). In older trees, the bark of the trunk is sometimes too thick to be attacked by gray squirrels but those can still strip secondary branches of the crown (Mayle *et al.* 2003).

In the UK, tree damage has been monitored since the 1950s and shows an increase of damage to coniferous species. This may be due to an enlargement of colonised upland areas mostly covered by conifers.

Between 1998 and 2003, Mayle *et al.* (2009) also monitored annual damage in a naturally regenerating oak forest (Forest of Dean, UK). They underscored the significant link between tree size and damage importance. Dominant oak trees and those above 7.5 cm of diameter at breast height were the most susceptible to stem damage which touched yearly 9 to 38% of trees and 2 to 17% of ring barked trees. Damage mainly occurred above 4m up the main stem. This suggests that young oak-dominated stands are susceptible to bark stripping damage from gray squirrels, associated to clear economic losses. Therefore, to reduce timber damage to oaks, control efforts should be done to reduce squirrel populations below damaging levels (Mayle *et al.* 2007).

Gray squirrels can also have important impacts on agricultural crops, mainly profitable cereals such as maize (Signorile & Evans 2007) and in Italy, the risk of damages to hazel plantations is also of concern (Currado *et al. in pres*).

D/ Genetic effects and hybridization

So far, no problems of hybridization could happen in Europe because of the genetic distance between the native red squirrel and the gray squirrel, although they belong to the same genus.

E/ Pathogen pollution

In the UK, a high mortality of red squirrels is due to a squirrel parapoxvirus (SQPV) (Scott *et al.* 1981, Sainsbury & Ward 1996, Sainsbury *et al.* 2007, Bruemmer *et al*. 2000, Tompkins *et al.* 2002). The hypothesis of disease transmission through *S. carolinensis* has been suggested because the virus was not known in the country before gray squirrels importations (Sainsbury & Gurnell 1995, Bruemmer *et al.* 2000) and because similar poxviruses do exist in the North American gray squirrel population. In UK, Duff *et al.* (1996) only reported one case of mortality of a gray squirrel because of the parapoxvirus. In Ireland, some gray squirrels carry the poxvirus. In Italy, it has not been recorded in either *S. carolinensis* or *S. vulgaris* (Bertolino, 2008, CABI 2012).

In UK, after epidemiolocial studies, 60% of the gray squirrel blood tested showed antibodies for the SPQV, proving an exposure to infection but a later recovery (Bruemmer *et al.* 2000). Therefore, the infection is widely distributed in the gray squirrel population but its pathogenicity seems to be weak, indicating S*. carolinensis* could be considered as a possible reservoir host (Crouch *et al.* 1995, Bruemmer *et al.* 2000). The mechanism of virus transmission is poorly understood but Bruemmer *et al.* (2010) advocate for direct transmission, through physical contact or via common focal points where contamination could occur (CABI 2012). Therefore, caution is advisable when undertaking any management that could bring red and gray squirrels into contact or attract them to join at focal points, such as trapping or supplementary feeding (Bruemmer *et al.* 2010).

Unfortunately, the incidence of SQPV in red squirrels increases the replacement rate of red by gray squirrels by as much as 20 times (ISSG 2005). Previously, no immune red squirrels were reported but recently the situation has slightly evolved and a few cases of living immune red squirrels have been reported (Invasive Species Ireland 2012, Bertolino 2008, Sainsbury *et al*. 2008).

The epidemiological study led by Sainsbury *et al*. (2008) to investigate the transmission dynamics and the relative pathogenicity of the virus between squirrel species was really needed. The distribution of cases of SQPV disease in the UK was studied according to woodland types, as a measure of squirrel density. The mains findings are that :

- the virus only occurred in areas inhabited by seropositive gray squirrels, and both (*S. carolinensis* and SQPV) geographically expand in the same way, supporting the idea the gray squirrel plays a role as a reservoir host of the virus;
- in Scotland, Ireland, northwest England and Italy, no red squirrels showed poxvirus antibodies. (Sainsbury *et al*. 2008);
- but recently, some individuals of free-living red squirrels apparently survived exposure to SQPV (immune response) which suggests a modification in the host-parasite relationship and a possible hope to develop an effective vaccine to better manage red squirrels populations in the future.

Harris *et al*. (2006) do not agree with a gray squirrel intensive elimination abovementioned. According to these authors, most gray squirrel trappings use warfarin (a dangerous rodenticide) while only live trapping and/or shooting are normally allowed and gray squirrel destruction is mainly done to protect timbers from bark stripping more than to protect red squirrel populations. No biological control method is currently available to limit grey squirrels populations (e.g. an immunocontraceptive) while big amounts of money have been unwisely invested in some researches. Moreover, the previous attempts to reduce *S. carolinensis* populations in Great Britain were always unsuccessful (except on islands). For Harris *et al*. (2006), controlling gray squirrel numbers to conserve *Sciurus vulgaris* is not a practical solution to adopt in Great Britain. Finally, red squirrel populations have been fluctuating in Great Britain all over centuries and have sometimes been reintroduced from populations of the European continent. Thus, the same authors consider that *Sciurus vulgaris* is not threatened at the European scale and could be easily reintroduced in case of extinction in the UK.

E/ Effects on ecosystem functions

The impacts of gray squirrel introductions on recipient ecosystems are not easy to enlighten. However, Mayle (2004) suggested that gray squirrel barkstripping could cause a lack of recruitment of trees into the canopy and have particular effects in semi-natural beech forests causing a loss of associated fungi and invertebrates. Therefore, the structure and composition of these forests could be affected by feeding on seeds and plant bulbs, like English bluebells (*Hyacinthoides nonscripta*), preventing their regeneration (ISSG 2005). On the other hand, the gray squirrel may have a positive impact on the seed dispersal by its scatterhoarder behaviour and, thus, contribute to woodland regeneration (Linzey *et al*. 2008). For example, Laborde & Thompson (2009) have shown that *Sciurus carolinensis* was the most important disperser of hazelnuts into the grassland in Derbyshire (UK).

ENVIRONMENTAL IMPACTS

It is likely that a gray squirrel establishment in Belgium and neighbouring areas would induce problems of herbivory, particularly because of its bark stripping behaviour in woodland areas which could sometimes lead to ecosystemical changes. Besides that, the problem of exclusive competition with the native red squirrel is particularly worrying in terms of nature conservation. For the most part of the aforementioned authors, *Sciurus carolinensis* clearly drives *S. vulgaris* to extinction where both species co-occur because of competitive exclusion and poxvirus (SPQV) transmission from gray to red squirrels. Where the virus is present, red squirrel displacement is much faster than in areas because *S. carolinensis* is a virus reservoir. Problems of competition with some forest birds could also be due to gray squirrel densities despite there is no strong evidence for it.

2.2.2 Other impacts

A/ Economic impacts

As already explained, gray squirrels became a serious threat for commercial hardwood timber production in the European recipient areas where it was introduced (Bruemmer *et al*. 2000). The bark stripping behaviour of *S. carolinensis* has been discussed previously. It can damage timbers but it can also lead to the death of many trees. Significant economic impacts due to *Sciurus carolinensis* have been pointed out in many publications especially in the United Kingdom and Italy, but not many estimates to assess economic impacts.

However, Broome & Johnson (2000) have given an estimate of squirrel damage costs to forest industry in Great Britain. For this, they considered, by area, the proportion of vulnerable trees of the most susceptible species (beech, sycamore and oak) aged between 10 and 40 years (Gurnell & Pepper 1988, Kenward 1989), and presenting squirrel damage. Their evaluation reached up to 10 million pounds for the British Isles. The same level of costs was defined by Lawton *et al.* 2010 for the year 2003.

From northern Italy, the progression of the gray squirrel across the Alps seems rather unavoidable. Thus, its propagation to central Europe has to be seriously considered because, moreover the threat it will cause to the red squirrel, it will almost certainly have dramatic repercussions for forest management even if not precisely estimated (Gurnell & Lurz 1997). Furthermore, current national policies aiming to increase the level of broadleaf planting are gravely destabilized by the gray squirrel progression (IUCN 2005, Harris *et al*. 2006).

B/ Social impacts

Studies about *Sciurus carolinensis* mainly mention environmental and economic impacts but their presence can also include some social negative effects for humans. For example, in urban areas, gray squirrels can sometimes become garden pests by digging up bulbs and eating the bark of ornamental plants (CABI 2012). In North America, reported damage concerns garden depredation, incurs, cable gnawing (Chapuis & Marmet 2006). However, squirrel species still have a strong appeal to humans (Harris *et al*. 2006, Bertolino & Lurz 2011) which explains their popularity in the native range as well as in new recipient areas (CABI 2012). On the other hand, because of the ecological problems due to the gray squirrel in Europe it is not often seen as a kind species. Therefore, it may even be trapped to be eaten (Schockert 2010, UNEP-WCMC 2010) which can be considered as a positive experiment by one part of the citizens. It also occcurs in the native range of *Sciurus carolinensis* (Mississippi) where gray squirrels are harvested for food (CABI 2012). In the United States, the gray squirrel hunting concerns an annual amount of 40 million individuals for an economic imput of 200 million dollars (Chapuis & Marmet 2006).

STAGE 3: RISK MANAGEMENT

3.1 RELATIVE IMPORTANCE OF PATHWAYS FOR INVASIVE SPECIES ENTRY IN BELGIUM

Two introduction pathways have to be taken into account for *Sciurus carolinensis* arrival in Belgium. The first one is linked to exotic squirrel importations and trade through pets shops or private citizens. According to the UNEP-WCMC survey (2010): such a trade has to be considered as a potential problem for gray squirrel introduction, especially because this species is present in neighbouring countries (United Kingdom, Ireland). If animals are kept in enclosures (pet retailers/private citizens) there is a risk that they reach wild habitats by escape or release. Only some individuals may establish a founding population, as shown in England and Italy. However, because of incomplete information about squirrel trade in Europe, the level or risk remains hard to assess. Though, knowing the appeal tree squirrels have generally on humans, this risk is especially of concern.

The second pathway of introduction would be a natural colonization from Italy according to the predicting models of gray squirrel spread developed by different authors. Of course, it will take time and thus, it is not of critical concern for the moment for our country... But the first threatened countries being France and Switzerland, it is worrying enough to consider preventive common actions (by prohibition, control, etc.) at a European level in order to better cope with the gray squirrel spread and its severe potential effects on tree management and red squirrel population decline.

3.2 PREVENTIVE ACTIONS

(i) Prohibition of organism importation, trade and holding

Many environmentalists of different countries have claimed for better legacy policies accross Europe to improve the gray squirrel population control (Bruemmer *et al.* 2000, Gurnell & Lurz 1997, Lurz *et al.* 1998, Mayle 2004, Genovesi 2002, Bertolino 2009, Bertolino & Lurz 2011).

In areas where the gray squirrel has been introduced, its range is still growing as well as the red squirrel displacement and other negative impacts on biodiversity and forestry (Mayle 2004). But so far, in most of the European cases, eradication is not a realistic option anymore.

A general wildlife management strategy in continental Europe is absolutely necessary because all countries don’t invest the same energy to prevent introductions of exotic species on their territory (Genovesi 2005). Moreover, the continuous increase of animal trade during the last decades has been a main cause of species introductions (Westphal *et al.* 2008). Thus, squirrels are still sold as pets increasing the introduction potential of *Sciurus carolinensis* in Belgium and neighbouring countries. Therefore, Bertolino (2009) and Bertolino & Lurz (2011) already suggested trade recommendations and interdictions as a global strategy on introduced species (Bertolino 2009, Bertolino & Lurz 2011). Such policies are especially essential when a risk on fauna, flora or/and ecosystems has been pointed

out in at least one European country. Many state authorities banned the release of exotic animals in the wild after a successful establishment of these alien species on their territory.
Beside a strong European policy, there could be a better control through the World Trade Organization for signatory states for sanitary or phytosanitary reasons.

Finally, the importation of alien species should be prohibited through a regular implementation of the European Union list of the Annex B of European Community Regulation no. 338/97 (the European Union Wildlife Trade Regulation that puts into effect the CITES within the European Union). Only some species representing major threats for native species belong to that list (Shine 2006). However, recently, three squirrel species, including *Sciurus carolinensis*, are now included by the CITES (Bertolino & Lurz 2011).

Bertolino & Lurz (2011) also suggest a systematic risk assessment procedure for traded tree squirrel species when their invasiveness potential presents a high level of risk in neighbouring countries or on the national territory, which is the case for the gray squirrel.

(ii) Use of specific holding conditions and effect of prohibition of organism introduction into the wild

Squirrels imported by the way of pet shops, private citizens and zoos are at risk of release or escape (Bertolino 2009). Use of stricter rules on importation and possession is therefore the most efficient approach to avoid risky introductions in the wild, followed by eradication actions or long-term containment or control (Shine *et al.* 2008, Bertolino 2009). If a gray squirrel detention is confirmed, prompt measures have to be taken by the authorities to remove or sterilize the animals.

3.3 CONTROL AND ERADICATION ACTIONS

(i) Can the species be easily detected at early stages of invasion (early detection)?

In countries where *S. carolinensis* is already present, Newson *et al.* (2010) advice a yearly survey to estimate gray squirrel population trends, in order to detect yearly changes in species relative abundance. In the UK, the gray squirrel belongs to a category of nine commonly sighted mammals (Newson & Noble 2006) for which such surveys help to better follow the species progression in the wild.

For Mayle (2004), it is important to target gray squirrel control in time and space to increase cost-effectiveness of control actions and reduce the numbers of animals killed. A good collaboration between various actors (such as landowners, hunters and forestry managers) is thus necessary to quickly detect gray squirrels and launch prompt control actions. However, since more and less sixty years, unsuccessful attempts have been made to eradicate the gray squirrel in the United Kingdom (Harris *et al*. 2006). Now, the gray squirrel is common, easy to detect and enjoyed by the public... Therefore even if an eradication would be possible, it would not be a desirable option anymore.

In the European countries where *Sciurus carolinensis* is present, the species already overpassed the level of early stages of invasion. It is why predicting models for gray squirrel spread have been build by different authors (Lurz *et al.* 2001, Rushton *et al.* 2000, Bertolino *et al.* 2008). Predictions related to the actual situation in northern Italy confirm the future establishment of the gray squirrel throughout central and northwest Piedmont and to the border with France within some decades (Bertolino *et al.* 2008). Since late 1990s, the species has been classified as impossible to control effectively once reaching pre-alpine forests where it will find continous woodlands to reach France (Lurz *et al.* 2001, Bertolino *et al.* 2008). Therefore, the gray squirrel spread to Eurasia is already on... and seems ineluctable.

(ii) Are they some best practices available for organism local eradication?

In Great Britain, *S. carolinensis* has been subject to wide control and eradication methods such as trapping, shooting and poisoning (Dagnall *et al.* 1998, Palmer *et al.* 2007). Although a high number of gray squirrels killed, the hunting program was ended because squirrel populations had not been reduced to a manageable level, the problem is even suggested to have grown worse despite the effort (Sheail 1999, Harris *et al*. 2006, Palmer *et al.* 2007). However, it is not known if the removal of so many individuals has slowed their population expansion (Palmer *et al.* 2007). The poisoning program, even though believed to be more efficient for squirrel control, has been confronted with pressure from animal rights groups (Dagnall *et al.* 1998, Sheail 1999).

Mayle (2004), Bertolino & Genovesi (2003) and many other authors encourage lethal methods of control as the only efficient option to contain gray squirrel populations and slow down their spread. Two aims are distinguished: the first one is to prevent tree damage, the second to help the red squirrel conservation where is still occurs (CABI 2012).

Trapping efforts have revealed an interesting effectiveness where *S. carolinensis* populations are still limited. In Italy, during two trapping sessions (8 days; 162 traps; 2.3 traps/ha of wood) preceded by a pre-baiting session of 2 weeks (Bertolino & Genovesi 2003). Traps were covered with black plastic sheets, baited with maize and checked once a day. During these 2 trapping sessions, 188 gray squirrels were caught which was supposed to represent half of the local population. Moreover, no non-target species were caught. After being trapped, an euthanasia procedure was used for the gray squirrels. It has been very effective in minimising stress in the animals (Bertolino & Genovesi 2003). The squirrels reach unconsciousness in less than one minute (Scagliarini,unpublished) with halotane (a tranquilliser that specifically reduces stress in rodents) and are easy to euthanize in the field (Bertolino & Genovesi 2003). However, because of legal actions led by animal rights associations, the program was stopped.

Control efforts to prevent tree damage have to target a population reduction around sensitive sites and before the damage occurs (Mayle 2004). This period corresponds to early spring, when there is food scarcity. Thus, the attractivity of baits is stronger and squirrels easier to catch. The treated area must not be the vulnerable areas but the mature woodland close to these areas, where gray squirrels will concentrate.

In the United Kingdom, in places where *S. vulgaris* occurs, live-traps and shooting are used to control gray squirrels (Mayle *et al.* 2003, Lawton & Rochford 2007). The warfarin is used for poisoning (on wheat) if no red squirrels or pine martens occur in the treated area, but in the European Union this compound is forbidden. The warfarin baits are distributed from hoppers and may only be used between mid-March and mid-August (Mayle 2004). Such baiting is interesting because its only needs one operator, can be used in large areas and is not that expensive (7 to 11 pounds per ha) (CABI 2012). The poisoning program, even though believed to be more efficient for squirrel control, has been confronted with pressure from animal right groups (Dagnall *et al.* 1998, Sheail 1999) because collateral effects caused by the rodenticide on the native fauna were denounced (Harris *et al*. 2006) However, because of the presence of non-target species in Belgium, this method should be totally avoided. Live trapping would therefore be one of the best method to retain for Belgium and neighbouring countries in case of *S. carolinensis* emergence, maybe connected with shooting. The CABI (2012) recommends the use of baited live-traps, tunnel trapping and shooting. Complementary studies also try to increase the bait attractiveness to gray squirrels in areas where food supply is low (coniferous woodlands) (Mayle 2004).

Besides euthanasia, an other chemical method was experimented in the UK to control gray squirrel reproduction through immuno-contraception (Pepper & Moore 2001, Mayle 2004). However, the results are controverted (Harris *et al*. 2006). The technique is still under investigation (UNEP-WCMC 2010).

Kenward and Dutton (1996) suggested to adjust planting and management prescriptions to minimise bark stripping and important economic losses (commercial woods). However, according to Mayle (2004), the important damage reported from Farm Woodland schemes implies that these sites are particularly at risk. Thus, new studies are needed to evaluate the impact of 'continuous cover' woodland management systems on tree growth, bark character and gray squirrel damage levels.

The use of geographical information systems (GIS) to identify potential vulnerable areas to gray squirrel damage should also be recommended regarding the species spread and its densities.

Finally, considering the problems encountered in Italy (and for a lesser part in UK) with animal right groups, a good communication about the problematics has to be done to better inform and convince the public of the actual threats linked to gray squirrel emergence and expansion (Schockert 2010).

(iii) Do eradication and control actions cause undesirable consequences on non-target species and on ecosystem services?

In the United Kingdom, the use of warfarin is forbidden in areas where red squirrels and martens are present that could be at risk of poisoning by the rodenticide instead of gray squirrels (Mayle 2004, Harris *et al.* 2006, CABI 2012). So far, due to such a potential impact in our country where these native species are present, poisoning methods should be avoided to control emerging gray squirrel populations.

(iv) Could the species be effectively eradicated at early stage of invasion?

If the number of individuals is not important (from some to some tens of individuals), it is likely that the eradication could be an effective control action, like it was done in Trecate (Bertolino & Genovesi 2003) when the municipality released 3 pairs of gray squirrels in a public park. In this case, trapping sessions led two years after the release of these animals seem to have been successful. But if the population would have grown, eradication attempts would have become difficult or even unfeasible... At least, considering the threats the gray squirrel may represent for native fauna and flora, it is necessary to deploy the best methods of eradication as fast as possible in case of new introductions. A systematic eradication control has been successful in Australia where the gray squirrel was introduced in 1880 (Seebeck 1984, Koprowski 1994).

(v) If widely widespread, can the species be easily contained in a given area or limited under an acceptable population level?

The difficulty of containment of gray squirrel existing populations in Europe gives evidence of the threats due to this exotic species. Different studies have been done, especially in the UK and Italy (see abovementioned references), to show the ineluctable character of the gray squirrel continuous spread in these countries. Some undergoing control efforts seem efficient to maintain local populations of *S. carolinensis* under a certain level (e.g. to reduce tree damage) but it needs effort, money and time. As widely mentioned, targeted effects are more difficult or impossible to attain when other problems co-occur, which is really problematical in the case of squirrel poxvirus presence among the gray squirrel population.

At least, in the UK, the species is naturally confined to its insular context but the situation is not comparable in Italy. All the studies done to enlighten solutions for gray squirrel containment in northern Italy have pointed out the powerlessness to manage the situation. It is at most possible to slow down a bit the gray squirrel spread, but not to prevent its spread in the pre-alpine continuous forests (Lurz *et al.* 2001, Bertolino 2008).

In Great Britain, *S. carolinensis* has been subject to wide control measures and eradication methods such as trapping, shooting and poisoning (Dagnall *et al.* 1998, Palmer *et al.* 2007). Altough a high number of gray squirrels were killed, the hunting program was ended because squirrel populations have not been reduced to a manageable level, maybe the problem is even worse despite the efforts invested (Sheail 1999, Palmer *et al.* 2007). However, it is not assessed if the removal of these individuals has slowed their population expansion (Palmer *et al.* 2007).

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La CiEi est chargée depuis novembre 2009 de coordonner les actions visant à limiter les dommages causés par les espèces invasives en Wallonie. Ses activités se fondent sur l'engagement du Gouvernement wallon à prévenir l'installation de nouvelles espèces invasives et de lutter contre celles dont la prolifération pose problème

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