Ecography

**ECOG-02769**
Marini, L., Økland, B., Jönsson, A. M., Bentz, B., Carroll, A., Forster, B., Grégoire, J.-C., Hurling, R., Nageleisen, L. M., Netherer, S., Ravn, H. P., Weed, A. and Schroeder, M. 2016. Climate drivers of bark beetle outbreak dynamics in Norway spruce forests. – Ecography doi: 10.1111/ecog.02769

# Supplementary material

**APPENDIX 1**

**Detailed description of the regional time-series: general info about climate, spruce forests and sampling methods**

In the following sections we will describe the climate and the spruce forests occurring in the 17 study areas included in the study. Moreover, we will describe the method of collection of forest damage by *Ips typographus* and storms.

<u>AUSTRIA (Alpine region)</u>

**General info**

The study region comprises all 9 federal states of Austria with a total area of 83,879 km². Forty-seven % of the landscape is covered by forests, which amounts to a total of 3,960,000 ha (2006-2010). Due to the high topographical diversity there are big regional differences in precipitation and temperature regimes. The eastern part of Austria is characterised by a Pannonian climate with low precipitation, hot summers but only moderately cold winters, while the West is influenced by the Atlantic. High precipitation (except inner Alpine valley regions such as the upper Inntal), short summers, long winters are typical for the alpine climate (www.austria.info). Mean annual temperatures (1971-2000) may vary between 4.5°C (St. Anton/Arlberg) and 9.3°C (Bad Radkersburg), precipitation (1971-2000) between 779 mm (Linz) and 1792 mm (Feuerkogel) (www.zamg.ac.at).

**Spruce forests**

Norway spruce is the dominant tree species in Austria, with a proportion of 53.6% (2006-2010) and a growing stock of 694,853,000 m³ (forest inventory 2007/09). Contrary to the artificial spruce forests of the lowlands, Norway spruce grows naturally in the mountains. Nevertheless, naturally mixed stands were replaced by pure spruce stands also at higher altitudes. In 2010, removal of conifer wood amounted to 15,296,643 m³ without bark, which was 1.35% of the total growing stock (conifers and deciduous trees). Harvest of forests is restricted to areas not larger than 2 ha by forest law. Commonly applied management practices are thinning and shelter-wood systems as well as removal of single or small groups of mature trees.

## Data on bark beetle damage

Data on bark beetle damage were compiled by the Federal Research and Training Centre for Forests, Natural Hazards and Landscape (BFW) based on the documentation of forest damaging agents by forest inspectors on county level. These data are available since 1944, relate to all private and public forests and are regularly published in special editions of "Forstschutz Aktuell" (e.g. Krehan et al., 2012). The yearly inventory comprises 72 biotic and abiotic damaging agents, whereby the amount of timber damaged by bark beetles is given in million $m^3$. The cooperation with the forest inspectors on county level (241 units for 71 forest inspectories in 2013) allows for an easy and representative collection of damage information for the whole forested area of Austria.

## Data on forest damage by storms

Data on storm damage are also based on the documentation of forest damaging agents by forest inspectorates on county level and given in million $m^3$ thrown timber. Storm and snow damages are distinguished only from 2000 onwards, while data available for the period 1946-1999 relate to both damaging agents. Although the exact amount of damaged Norway spruce was not specified, the predominant part of damaged wood can be attributed to this tree species due to its dominance and susceptibility to wind throw.

## Ips voltinism

Flight periods of the bark beetle *Ips typographus* are monitored on 60 representative sites in all countries of Austria (www.borkenkaefer.at) under the coordination of BFW. Monitoring results can be retrieved for each year since 2005. At most localities, pheromone trap catches start between April and May and occur over a period of 4 to 5 months till September. After a distinct spring swarming period, trap catches again increase in summer (June to August), which points to bivoltinism at the majority of monitoring sites. Although univoltine behaviour may be more frequent at higher altitudes, high solar irradiation and thus increased phloem temperatures at exposed localities allow for the establishment of a second generation as shown by the phenological model PHENIPS (Baier et al., 2007).

## References

http://www.austria.info

http://www.borkenkaefer.at

http://www.zamg.ac.at

Baier P. et al. 2007. PHENIPS—a comprehensive phenology model of *Ips typographus* (L.) (Col., Scolytinae) as a tool for hazard rating of bark beetle infestation. – Forest Ecol. Manag., 249, 171–186.

Krehan H. et al. 2012. Borkenkäfer-Situation 2011. Schäden deutlich geringer. In: Forstschutzsituation 2011 in Österreich. Erhebungen und Diagnosen des BFW und Dokumentation der Waldschädigungsfaktoren 2011. – Forstschutz Aktuell, 56, 11–15.

BELGIUM (Wallonie)

**General info**

Wallonie is one of Belgium's three regions, at the south of the country. It covers 16,844 km$^2$, with forest stands over 478,000 ha. 252,000 ha are occupied by broadleaves and 226,000 ha with conifers. 238,000 ha belong to various levels of public authorities and are managed by the Walloon forest service, whilst 240000 ha belong to private owners, with 70% of the stands covering less than one ha (Laurent and Lecomte 2006). Wallonie's highest location is at 694 m a.s.l. but roughly one third of the territory is above 300 m a.s.l.

**Climate**

The Belgian climate is mild (average temperature: 3.3°C in January, 18.4°C in July; average rainfall: 76.1 mm in January, 73.5 mm in July).
(http://www.meteo.be/meteo/view/fr/360955-Normales+mensuelles.html)

**Spruce forests**

Spruce is the most common species in conifer stands, covering 168,000 ha. All spruce stands are plantations. In 1999, 11.1% of the planted area was below 300 m and 26.7% was above 500 m. The median age class was the 30-39 year class (with 13.6% of 1-9 years old stems due to replantation after the 1990 storm), and the mean growing stock was 338 m$^3$/ha (http://environnement.wallonie.be/dnf/inventaire/chifp2.htm). Clear felling is the general management option, over a maximal allowed unitary area of 5 ha.

**Data on forest damage by storms**

A database managed by the Département Nature et Forêts of the Public Service of Wallonie gathers the information from yearly stand inventories since 1996 (Franklin et al. 2004): wind-felled and broken trees; trees attacked by *Ips typographus* (all data in m³). In this article, we used the 1993-2011 data. The average volume of wind-felled spruces during this period was 33,144 m³ (SD: 48,708m³), and a maximum in 2007 (197,740 m³).

**Data on bark beetle damage**

From the database of the Département Nature et Forêts (Public Service of Wallonie), on the average, 6,019 m³ (SD: 5,599 m³) were attacked yearly, with peaks in 1995 and 1996 (23,280 and 15,374 m³, respectively). Wind-felled trees are attacked first, followed by standing trees (Grégoire et al. 1997; Grégoire et al. 2009). In the absence of interspecific competition, wind-felled trees keep their resources for *Ips typographus* during more than one year (Louis et al. 2014; 2016). Attacked wind-felled trees were calculated to produce up to 30,000 emerging offspring per m³ (Gonzalez et al. 1996). During the nineties, pheromone-baited traps and trap trees were massively used in an attempt to control *Ips typographus* (Raty et al. 1995; Grégoire et al. 1997). Around the end of this decade, mass-trapping was discontinued when it became clear that most of the beetles caught in the traps are not those that emerged locally (Franklin and Grégoire 1999, 2001; Franklin et al. 2000).

**Ips voltinism**

There are two generations per year, as recorded yearly by the Walloon Observatory of Forest Health, with the first flight from late March to late May, depending on the year's temperature, and the second flight in July-August (http://owsf.environnement.wallonie.be/fr/index.html?IDC=5636). In particularly warm years, a third generation can be observed, flying in late August and September. The species is therefore bivoltine in the large majority of the sites and years (>90% of cases).

**References**

http://www.meteo.be/meteo/view/fr/360955-Normales+mensuelles.html

http://environnement.wallonie.be/dnf/inventaire/chifp2.htm

http://owsf.environnement.wallonie.be/fr/index.html?IDC=5636

Franklin A. and Grégoire J. - C. 1999. Flight behaviour of *Ips typographus* L. (Col., Scolytidae) in an environment without pheromones. – Ann. Scie. Forest., 56, 591–598.

Franklin A. et al. 2000. Recapture of *Ips typographus* (Col., Scolytidae) with attractants of low release rates: localized dispersion and environmental influences. – Agric. For. Entomol., 2, 259–270.

Franklin A. and Grégoire J. - C. 2001. Dose-dependent response and preliminary attraction range of *Ips typographus* (Col., Scolytidae) to pheromones of low release rates. – J. Chem. Ecol., 27: 2425–2435.

Franklin A. et al. 2004. Using sales of infested timber to quantify attacks by bark beetles: testing a cost-effective method for the assessment of population levels. – Ann. For. Scie., 61, 477–480.

Gonzalez R. et al. 1996. A sampling technique to estimate within-tree populations of preemergent *Ips typographus* (Coleoptera, Scolytidae. – J. Appl. Entomol., 120, 569–576.

Grégoire J.-C. et al. 2009. Méthodes d'évaluation des attaques d'*Ips typographus* (Coleoptera, Scolytinae) en pessière. Pp. 77-99 *in* Y. Birot, G. Landmann & I. Bonhème (Eds.), La forêt face aux tempêtes. Quae éditions, Versailles. 433 pp.

Grégoire J.-C. et al. 1997. Pheromone mass-trapping: does it protect windfalls from attack by *Ips typographus* (Coleoptera: Scolytidae)? In: Grégoire, J.-C. et al. (Eds.), Integrating Cultural Tactics into the Management of Bark Beetle and Reforestation Pests. Proceedings of the IUFRO Conference, 1–4 September. (1996). USDA, Forest Service General Technical Report NE-236, Vallombrosa, Italy, pp. 1–8.

Laurent C. and Lecomte H. 2006. La composition, l'évolution et l'exploitation de la forêt. État de l'environnement wallon. – Rapport analytique, 2007, 184–195.

Louis M. et al. 2016. Fallen trees' last stand against bark beetles. – For. Ecol. Manag., 359, 44–50.

Louis M. et al. 2014. Exploiting fugitive resources: How long-lived is "fugitive" ? Fallen trees are a long-lasting reward for *Ips typographus* (Coleoptera, Curculionidae, Scolytinae). – For. Ecol. Manag., 331, 129–134.

Raty L. et al. 1995. Mass trapping of the spruce bark beetle *Ips typographus* L.: traps or trap trees? – *For. Ecol. Manag.,* 78, 191–205.

<u>ITALY (Friuli-Venezia Giulia)</u>

**General info**

The study area was the mountainous region of Friuli-Venezia Giulia (NE Italy), an area of 7,844 km$^2$ on the southern border of the European Alps. Rainfall regime in the areas covered by spruce forests varies between 1000 and 1200 mm yr$^{-1}$ while mean annual temperatures varied between c. 12° and 4° C (between the lowest and highest elevations) with an average of c. 8°C.

**Spruce forests**

Norway spruce forests cover c. 66,620 ha with a mean growing stock of 290 m$^3$ ha$^{-1}$ and 310 m$^3$ ha$^{-1}$ for mixed and pure formations, respectively. Artificial spruce forests cover c. 2,400 ha (3.6% of total spruce forests) and are distributed between 100 and 1500 m with a mean of 895 m (SD=288 m), while native spruce forests covered 64,200 ha (96.4% of total spruce forests) and were distributed between 300 and 2000 m with a mean of 1200 m (SD=272 m). Management practices are mainly based on the shelter-wood system or on clear-cut over small surfaces (<1 ha) in which mature trees (120–180 years) are felled. In managed spruce forests trees with more than 200 years are usually absent or rare and remnant stands with 'old-growth structures' tend to be scattered and small-size d in the Italian Alps. The resulting forest landscape was characterized by a very heterogonous mosaic of small management units (<30-40 ha) with different structures and ages.

**Data on bark beetle damage**

Data on bark beetle attacks was obtained from the phytopathological forest inventory of the region (BAUSINVE, http://www.regione.fvg.it/). The database included data from a long-term intensive forest health monitoring project covering a 16 year period (1994-2009). *I. typographus* has a natural tendency to aggregate and produce easily recognizable clusters of trees that are killed in any given year (hereafter labeled 'spots'). For each year in our time series, the sampling systematically covered the whole region via ground-based surveys of a team of local foresters and entomologists. Each spot was visited to identify the biotic agent causing tree mortality and to record the number of killed trees, the volume of timber loss ($m^3$), and the spatial coordinates. Using these data we built a time series of annual timber loss for the whole region by summing the volume of trees killed ($m^3$) in all the spots occurring each year. Estimates of annual timber loss included also spots that were detected until spring of the following year to allow for the delay between beetle attacks of late summer by second or even third generations and the death of tree foliage in the next spring. In the few cases of uncertainty the ground-survey helped discriminating between a new spot and old spot of the previous year.

**Data on forest damage by storms**

We also quantified the annual amount of timber loss due to these abiotic events. Data were retrieved from the forest damage inventory of the region (BAUSINVE, http://www.regione.fvg.it/). Forest damage from abiotic events were normally small and spatially localized with a mean of 135 $m^3$ (SD=353 $m^3$) per event. The mean annual amount of forest damage due to abiotic events in the region was ca. 7,200 $m^3$ (c. 20-30 ha).

**Ips voltinism**

The flight activity of I. typographus was very extended and occurred over a period of about 4 months (May–August). Generally, it is possible to detect two main periods of capture of I. typographus , the first occurring in spring (May to mid-June) and the second in summer (mid-June to August). Spring captures occur before the pheromone change and include overwintering adults, which, when the mean air temperature is about 18 °C, fly looking for suitable spruce trees from where to start the first generation. Summer captures, occurring from the end of June until September, include emerging adults of the first generation, which fly towards new hosts. Although both the flight periods have the same duration (about 8 weeks) , spring captures include about the 80% of all beetles caught (Faccoli and Stergulc 2004). The species is therefore bivoltine in the large majority of the sites and years (>90% of cases).

**References**


BAUSINVE, http://www.regione.fvg.it/

Faccoli M. and Stergulc F. 2004. *Ips typographus* (L.) pheromone trapping in south Alps: spring catches determine damage thresholds. – J. Appl. Entomol., 128, 307–311.

Marini L. et al. 2012. Climate affects severity and altitudinal distribution of outbreaks in an eruptive bark beetle. – Climatic Change, 115, 327–341.


SWITZERLAND (Lowland area and Mountain area)

**General info**

The two Swiss study areas are based on the five main forest production regions of Switzerland. They are long time defined and described by the Swiss National Forest Inventory (Brändli, 2010). Data of volume, growing stock, tree species and many other parameters are available. The area "Lowland" for this paper is compiled by the two production regions "Plateau" and "Jura" with a total of 428'000 ha of forests and the area "Mountain", compiled by the production regions "Pre-Alps" ,"Alps" and "Southern Pre-Alps" with a total of 806'000 ha of forests. In the "Lowland" area, more than 90% of the forest stands belong to the foothill zone and to the lower montane zone. In the "Mountain" area about 60% of the stands belong to the upper montane zone and the subalpine zone. Rainfall regime in the areas covered by spruce forests varies between 800 and 2000 mm $yr^{-1}$, while mean annual temperatures varied between c. 15° and 8° C in the "Lowland" and c. 11° and 4° C in the "Mountain" area.

**Spruce forests**

Mostly artificial spruce forest are grown in the "Lowland" area north of the Alps with a total volume of 62 Mio $m^3$ . In the "Mountain" area spruce forests have a total volume of 129 Mio $m^3$ and are mostly natural. Only 9 Mio $m^3$ of them grow in the Southern Pre-Alps. Lower elevations in alpine valleys are here often free of spruce. The mean growing stock in Switzerland is almost 370 $m^3$ $ha^{-1}$. It varies a lot, depending on sites, altitude and management, but some spruce stands can reach up to 800 $m^3$ $ha^{-1}$. In the "Lowland" area spruce forests are more intensely managed, often as mixed stands. In the "Mountain" area even and uneven aged spruce stands can be found, sometimes pure, sometimes mixed with silver fir, larch or broadleaf species. Large clear-cuts (>1 ha) do not occur in Switzerland.

**Data on bark beetle damage**

Data on *Ips typographus* attacks are compiled by the Swiss Forest Protection team at WSL (Swiss Federal Institute for Forest, Snow and Landscape Research) and are based on annual inquiries by the forest services of all the Swiss cantons. The return rate is about 95 to 98% percent. The yearly infestations are published in reports (Meier et al. 2015). The data are based on the harvest of infested trees in all, public and private forests. Additionally the field foresters estimate the volume of infested dead spruce that remain in the stands. Detailed data for every forest district are available since 1984.

**Data on forest damage by storms**

Data on storm damage are also collected and compiled by the Swiss cantons. Methods may vary from canton to canton. Data can be based on the harvest of damaged timber, but also on aerial photos or estimations by the forest service. WSL and FOEN (Federal Office of Environment) compile storm data on wind thrown timber in long year's collections (Usbeck et al. 2010). Most storm data include all tree species and do not specify the exact amount of damaged spruce. Spruce is more sensible to strong wind than most other tree species. That is why after big storm events, also the wind thrown amount of spruce was inquired and published (Forster et al. 2003).

**Ips voltinism**

Two full generations of *Ips typographus* normally only occur in the foothill zone and in some parts of the lower montane zone. Hence in the Plateau region *I. typographus* is bivoltine, as already described by Kuhn (1949). In the lower montane zone, there is quite a big difference in voltinism, depending on topography and weather. In cool to normal years, bivoltinism can be observed up to

1000 to 1200 m asl. In warm years two beetle generations can be found up to 1500 m asl., especially on sunny slopes (Forster, 1993). So, in the chosen “Lowland” area mostly bivoltine behavior occurs. In the “Mountain” area, univoltine behavior is common in the majority of the spruce stands. But in the lower and sometimes even in the upper montane zone, bivoltinism is possible and gets more frequent under the influence of climate warming. A model (Jakoby et al. 2015) shows how fast *I. typographus* develops and under what conditions two generations of *I. typographus* can be expected. First experiences show, that the model fits quite well to reality.

**References**

Brändli U.-B. (ed.) 2010. Schweizerisches Landesforstinventar. Ergebnisse der dritten Erhebung 2004–2006. Birmensdorf, Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft WSL. Bern, Bundesamt für Umwelt, BAFU. 312 p.

Forster B. 1993. Entwicklung der Borkenkäfersituation in den Schweizer Sturmschadengebieten. – Schweiz. Z. Forstwes., 144, 767–776.

Forster B., Meier F., Gall R., Zahn C. (2003). Erfahrungen im Umgang mit Buchdrucker-Massenvermehrungen (*Ips typographus* L.) nach Sturmereignissen in der Schweiz. Schweiz. – Z. Forstwes., 154, 431–436.

Jakoby O. et al. 2015. Borkenkäfer im Klimawandel – Modellierung des künftigen Befallsrisikos durch den Buchdrucker (*Ips typographus*). Eidg. Forschungsanstalt WSL, Birmensdorf, 45.

Kuhn W. 1949. Das Massenauftreten des achtzähnigen Fichtenborkenkäfers *Ips typographus* L. nach Untersuchungen in schweizerischen Waldungen 1946 bis 1949. Mitt. Schweiz. Anst. Forstl. – Versuchswesen, 26, 245–330.

Meier F. et al. 2015. Forstschutz-Überblick 2014. – WSL Berichte, 3, 23–32.

Usbeck T. et al. 2010. Increasing storm damage to forests in Switzerland from 1858 to 200. – Agric. For. Meteorol., 150, 47–55.

## FRANCE (Champagne-Ardenne, Lorraine, Alsace, Franche-Comté, and Rhône-Alpes)

**General info**

Data on the spruce bark beetle are available for 5 administrative regions: Champagne-Ardenne (25,606 km$^2$), Lorraine (23,547 km$^2$), Alsace (8,280 km$^2$), Franche-Comté (16,202 km$^2$) and Rhône-Alpes (43,698 km$^2$). These areas include both flat (200 m to 500 m of elevation) and mountainous areas: Ardennes (up to 600 m) in Champagne-Ardenne, Vosges (up to 1400 m) in Lorraine-Alsace, Jura (up to 1700 m) in Franche-Comté and North-Alps (up to the vegetation limit i.e. 2000m) in Rhône-Alpes. Statistical data are only available at the region scale (source: http://inventaire-forestier.ign.fr/spip/spip.php?article830).

**Climate**

At low elevation (<500 m), we can consider that climate is semi-continental with annual rainfall between 700 to 1000 mm and annual mean temperature between 8 to 10 °C (1° to 2° in January, 19° to 21° in July). With a higher elevation, precipitation increase gradually and the temperature decreases. The climate is typically mountain above 1000 m with annual rainfall exceeding 1000 mm (up to more than 2000 mm) and mean temperatures below 8 °C.

references : http://www.meteofrance.com/climat/france/

**Spruce forests**

Spruce is mainly present in mountainous area. It is only natural in Jura and North-Alps and of artificial origin (planted) in the other parts of the considered area (Source: http://inventaire-forestier.ign.fr/spip/spip.php?article830). Growing stocks vary between c. 100 to 200 $m^3$ $ha^{-1}$ (see Table 1 in the main text). Forest management is mostly based on clear cut on flat areas (up to 20 ha) and selective cutting in mountain areas.

**Data on forest damage by storms**

Annual amounts of timber loss due to abiotic events is unknown in detail. Only statistical data are available when a big event occurs as the storms in 1990 or 1999. In the months that followed the storms, regional surveys were conducted by the Forest Service and synthesized at national level by the Ministry of Agriculture. One of the problems of these surveys is that spruce is often mixed with silver fir. The indicated volumes are calculated retrospectively using percentages between spruce and fir in the forests before the storm from the National Forest Inventory.

**Data on bark beetle damage**

Data on Spruce bark beetle attacks are obtained by summing timber volumes sold each year. These figures have several limitations:

1) some neighboring healthy trees are sometimes sold with bark beetle wood

2) not all forests attacked by bark beetles are always harvested

3) in a few cases the year of the sales may not match the attack year

However, these biases can affect more the estimate of the magnitude of the attack rather than the inter-annul variation.

**Ips voltinism**

The flight activity of *I. typographus* depends on climatic conditions. At low elevation (<900 m) it may be very extended and occurred over a period of c. 5-6 months (April–September/October). At high elevation (>1000 m) it is restricted to the summer months (from mid-June to the end of August). Generally at low elevations, two generations are observed. A third generation is seldom observed (only hot, long summers such as those in 2000 or 2003). At high elevation *Ips typographus* is mainly univoltine. On average we can consider that spruce bark beetle is mainly bivoltine in Champagne-Ardenne, Lorraine, Alsace, Franche-Comté and univoltine in Rhône-Alpes.

**References**

http://inventaire-forestier.ign.fr/spip/IMG/pdf/L_IF_no02_tempetes.pdf

http://agreste.agriculture.gouv.fr/IMG/pdf/primeur120.pdf

Abgrall J. - F. and Soutrenon A. 1991. La forêt et ses ennemis. – Cemagref, 395 p., ISBN 2-85362-196-0.

Abgrall J. - F. 2000. La tornade de décembre 1999: risques sanitaires et stratégies de gestion. Expertise collective sur les tempêtes, la sensibilité des forêts et sur leur reconstitution. Coordonné par O. Laroussinie et S. Druineau (GIP ECOFOR), 29 p.

Nageleisen L. - M. 1999. Le point sur les pullulations de scolytes après les tempêtes de 1990. Actes du séminaire du 20 et 21 mai 1999 à Lametz (08). Doc. interne. DSF, Antenne Spécialisée, Nancy (Champenoux).

Nageleisen L. - M. 2000. La pullulation de scolytes dans le nord-est de la France de 1990 à 1997 suite aux tempêtes de février 1990. Les Cahiers du DSF, 1-2000, (La santé des forêts [France] en 1999) Ministère de l'Agriculture et de la Pêche (DERF), Paris, France, 2000, 45-49.

Nageleisen L. - M. 2001. Monitoring of bark and wood-boring beetles in France after the December 1999 storms. – Integr. Pest Manage. Rev., 6, 159–162.

Nageleisen L. - M. 2002. Le point sur les attaques des scolytes des résineux en fin d’année 2001 suite aux tempêtes de Décembre 1999 et les mesures de lutte mises en œuvre. Les Cahiers du DSF, 1-2002, (La santé des forêts [France] en 2000 et 2001) Ministère de l'Agriculture et de la Pêche (DERF), Paris, France, pp. 43-45.

Nageleisen L. - M. 2004. Les insectes sous-corticaux des résineux en 2002 : diminution inattendue des dommages dus aux scolytes. Les Cahiers du DSF, 1-2003/2004, (La santé des forêts [France] en 2002) Min. Agri. Alim. Pêche et Aff. Rur.(DGFAR), Paris, France, pp. 29-31 .

Nageleisen L. - M. 2004. Recrudescence des insectes sous-corticaux à la suite des extrêmes climatiques de 2003. La santé des forêts [France] en 2003, Min. Agri. Alim. Pêche et Aff. Rur.(DGFAR), Paris, France, 4p.

http://www.agriculture.gouv.fr/spip/IMG/pdf/

Nageleisen L. - M. and Roussel T. 2004. Les dispositifs de suivi intensif des scolytes de l'épicéa mis en place dans le Nord-Est de la France suite aux tempêtes de 1999: principaux résultats de l'étude DSF-Engref. Les Cahiers du DSF, 1-2003/2004, (La santé des forêts [France] en 2002) Min. Agri. Alim. Pêche et Aff. Rur.(DGFAR), Paris, France, pp. 69-72.

Nageleisen L. - M. 2005. Insectes sous-corticaux : des mortalités records dans l'est de la France en 2004.

(La santé des forêts [France] en 2004) Min. Agri. et Pêche.(DGFAR), Paris, France, 6 p.

http://www.agriculture.gouv.fr/spip/IMG/pdf/insectes_sous_corticaux.pdf

Nageleisen, L.-M. (2006). Insectes sous-corticaux des résineux en 2005 : poursuite de la pullulation de typographe de l'épicéa dans les montagnes de l'Est. (Bilan de la santé des forêts [France] en 2005) Min. Agri. et Pêche (DGFAR), Paris, France, 5 p.

http://www.agriculture.gouv.fr/spip/IMG/pdf/scolytes_2005.pdf

Nageleisen L. - M. 2009. L'estimation des dégâts liés aux scolytes après les tempêtes de 1999. in Birot Y., Landmann G., Bonhême I., La forêt face aux tempêtes, Ed. Quae, Chap. 5 pp. 69-75.

Rouault G. et al. 2006. Effects of drought and heat on forest insect populations in relation to the 2003 drought in Western Europe. – Ann. For. Sci., 63, 613–624

GERMANY (Niedersachsen, Baden-Württemberg, Rheinland-Pfalz, Thüringen, and Sachsen)

**General info**

The study area were five federal states of Germany, selected from a total of 14. The selection tried to represent different zones, so one of these federal states is in the north (Niedersachsen = Lower Saxony), one in the south (Baden-Württemberg = Baden-Wuerttemberg) and three in the mid of the country from west to east (Rheinland-Pfalz = Rhineland-Palatinate; Thüringen = Thuringia; Sachsen = Saxony). The area of Germany is about 357,375.62 km², the areas of the selected five federal states are 47,614.82 km² for Niedersachsen, 19,854.36 km² for Rheinland-Pfalz, 16,202.14 km² for Thüringen, 18,420.25 km² for Sachsen and 35,751.34 km² for Baden-Württemberg. All five federal states have typical proportions of areas, covered by spruce forests. Rainfall regime in Germany averages at typically 750 mm $yr^{-1}$ with bigger differences in the federal states (Niedersachsen 785 mm $yr^{-1}$, Rheinland-Pfalz 645 mm $yr^{-1}$, Thüringen 590 mm $yr^{-1}$, Sachsen 625 mm $yr^{-1}$ and Baden-Württemberg 730 mm $yr^{-1}$. In the last three decades, mean temperatures varied between 18.0°C and 0.4°C with an average of 8.87°C, all temperatures were a bit lower in higher regions, where most of the spruce stands exist.

**Spruce forests**

Norway spruce forests in Germany cover about 2,763,219 ha with a mean growing stock of 111 $m^3$ $ha^{-1}$. The five federal states, used in this study, show the following areas and mean volumes for spruce forests: Niedersachsen 189,448 ha (63 $m^3$ $ha^{-1}$), Rheinland-Pfalz 157,365 ha (78 $m^3$ $ha^{-1}$), Thüringen 198,282 ha (151 $m^3$ $ha^{-1}$), Sachsen 172,560 ha (139 $m^3$ $ha^{-1}$) and Baden-Württemberg 442,990 ha (151 $m^3$ $ha^{-1}$). Because almost all of the spruce forest stands are artificial, they are distributed via most altitudes, present in Germany (Niedersachsen -2 m/971 m/69 m; Rheinland-Pfalz 28 m/816 m/318 m; Thüringen 113 m/983 m/358 m; Sachsen 73 m/1216 m/290 m and Baden-Württemberg 85 m/1493 m/490 m). Management practices are mainly based on techniques like thinning from above and shelterwood system, clear cutting is rare and only on very small areas (<2 ha). Regular harvesting is in the age of 100 to 140 years (mean 120 year). The resulting forest landscape was characterized by a very heterogenous mosaic of small management units are most often between 5 to 10 ha with likewise structures and ages within the stands.

**Data on bark beetle damage**

Data on bark beetle attacks was obtained from several sources. Each federal state in Germany collects its own numbers and in some cases, it also prepare its own statistics. Most of the data was published in a German forest journal (AFZ 1980-2010, issues no. 7). Data not published in any way, was retrieved from the forest research institutes of each federal state. The articles included data from the forest enterprises, reported and compiled per federal state. Most of the data were estimations.

**Data on forest damage by storms**

Annual amounts of timber loss due to abiotic events were also retrieved from several sources. Most of the data was internal company, varying from state to state. Complements came from BfS. Forest damage from abiotic events were normally small and spatially localized. Since data was often not available on a per state basis, means and variations could only be computed for Germany in total (mean per year 6,338,000 $m^3$, max per year 73,800,000 $m^3$and SD 15,365,676 $m^3$). The relatively large mean annual amount of forest damage due to abiotic events in the study period came from the strong hurricane Kyrill in 2007.

**Ips voltinism**

The flight activity of I. typographus was very extended and occurred over a period of about 4-5 months (May–August/September). Generally, it is possible to detect two main periods of capture of I. typographus , the first occurring in spring (May to the beginning of June) and the second in summer (end of June to mid of July). Spring captures occur before the pheromone change and include overwintering adults, which, when the mean air temperature is about 16 °C, fly looking for suitable spruce trees at sunny edges from where to start the first generation. Summer captures, occurring from the end of June until September, include emerging adults of the first generation, which fly towards new hosts. Although both the flight periods have a similar duration (about 6 weeks) , spring captures include about the 80% of all beetles caught. The species is therefore bivoltine in the large majority of the sites and years (>90% of cases). Univoltism is not observed in Germany, three generation are seldom (only hot, long summers) and often not able to get ready.

**References**

AFZ/Der Wald 1980-2010. Allgemeine Forst-Zeitschrift/Der Wald. Waldschutz-Ausgaben (jährlich Nr. 7) http://www.forstpraxis.de/heftarchiv-333972.

BfS 2015. Bundesamt für Statistik. Statistiken zu Schadholz. https://www.destatis.de/DE/Startseite.html.

BWI3 2012. Bundeswaldinventur Ergebnisdatenbank. https://bwi.info/inhalt1.aspx.

Wikipedia 2016. CLINO-Perioden (30-jährige Temperaturmittelwerte). https://de.wikipedia.org/wiki/Zeitreihe_der_Lufttemperatur_in_Deutschland#CLINO-Perioden_.2830-j.C3.A4hrige_Temperaturmittelwerte.29

SWEDEN (S Sweden)

**General info**

The study area was southern Sweden with an area of 87,712 km$^2$. Rainfall regime in the areas covered by spruce forests varies between 600 and 1200 mm yr$^{-1}$ while mean annual temperatures varied between c. 8° and 5°C (between the lowest and highest elevations) with an average of c. 6.5°C. Mean elevation in this region is c. 155 m.

**Spruce forests**

Norway spruce dominated stands cover 39.4%, and in mixtures with other tree species 18.8%, of the total forest area of 5,435,000 ha. The mean growing stock of spruce for the whole forest area is 175 m$^3$ ha$^{-1}$ (i.e. also including clear-cuts, young stands and stands composed of other tree species). Almost the entire region is within the natural range of spruce (even though the proportion of spruce has increased strongly within the region as a result of forest management). There are no high mountains within the region and spruce is grown on all altitudes. Management practices are mainly based on clear-cutting forestry with even-aged stands which are thinned two to three times before final harvest at an age of 60–80 years. Average clear-cut size is 4.3 ha. The resulting forest landscape is characterized by a heterogonous mosaic of small stands (i.e. management units) with different tree species composition and ages. Remnant stands with 'old-growth structures' are generally only present in reserves which cover a very small proportion (2.6%) of all forest land.

**Data on bark beetle damage**

Data on bark beetle attacks was obtained from the Swedish Forest Agency. Estimates of volumes of trees killed by *Ips typographus* are based on a combination of estimates from local Forest Agency officials (for each district), inspections of reference forest properties and estimates of volumes of salvage cut killed trees from large companies and forest owner organizations.

**Data on forest damage by storms**

Data on volumes of storm-felled trees were obtained in the same way as beetle-killed trees (see above).

**Ips voltinism**

In Sweden *I. typographus* only hibernates as adult. In southern Sweden the flight activity of *I. typographus* generally starts in the latter part of April and ends in mid-August as recorded from pheromone-baited traps. The flight period consists of the main spring flight followed by one or more sister brood flights (Öhrn et al. 2014). New generation beetles starts to emerge from their breeding material in July. New generation beetles are also caught in pheromone traps at the end of the summer (recognized by lighter elytra colour). But confirmed records of bivoltinism (i.e. the new generation successfully completing development into adults before winter) are rare. The species is therefore univoltine in the large majority of the sites and years.

**References**

http://www.slu.se/skogsstatistik (Forestry statistics for Sweden)

http://www.smhi.se/klimatdata (Temperature and precipitation data, annual averages 1961-1990)

Öhrn P. et al. 2014. Seasonal flight patterns of *Ips typographus* in southern Sweden and thermal sums required for emergence. – Agric. For. Entomol., 16, 147-157.

NORWAY (SE Norway)

**General info**

The study area included the southeastern part of Norway (in Norwegian called "Østlandet") with a total area of 96,877 km$^2$. Rainfall regime in the area varies between 400 and 1500 mm yr$^{-1}$ while mean annual temperatures varies between c. 1° and 7° C within the study area.

**Spruce forests**

Forests dominated by Norway spruce cover c. 2.1 mill. ha, where 1.5 mill. ha has more than 70% spruce and a mean growing stock of 165 m$^3$ ha$^{-1}$, and the 0.6 mill. ha contain mixed forests with less than 70% spruce and a mean growing stock of 132 m$^3$ ha$^{-1}$. The whole area is considered native forest, even though planting is practiced in most of the area. The elevation ranges from 0 to 1200 m above sea level. Management practices are mainly based on stand rotation and clear-cut practice, where the stands are considered mature at an age of 60-120 years, and clear-cut areas are most often replanted within 1-2 years. The size of the clear-cut areas has a mean of 3.2 ha and a median of 2.1 ha. The resulting forest landscape is characterized by a mosaic of forest stands of various ages. The landscapes are topographic with a large variation in productivity of the spruce stands. In some areas, Scots pine (*Pinus sylvestris*) in dominant on the hill tops, while other areas (especially closer to the coast) mixed stands of spruce and deciduous trees are more common.

**Data on bark beetle damage**

Data on *Ips typographus* attacks are compiled by the Norwegian Forest and Landscape Institute (fused in Norwegian Institute of Bioeconomy in 2015) and are based on inquiries of annual estimates from local forest agency officials in all of the eight counties in SE Norway. The estimates are based on field surveys, subjective estimates, and in some cases surveys by airplane.

**Data on forest damage by storms**

Data on storm damage is also compiled by the Norwegian Forest and Landscape Institute (fused in Norwegian Institute of Bioeconomy in 2015). For the period 1969-1980, the data were based on the estimates of Worrel (1983). In the period 1985-2010, the estimates of storm damages were based on insurance taxations after storms by Skogbrand (www.skogbrand.no). For years and counties that were not covered by Worrell (1983) or the taxations by Skogbrand, data were supplied from estimates conducted by local forest agency officials.

**Ips voltinism**

The flight activity of *I. typographus* starts when a minimum temperature sum is reached in late spring and on days with air temperature above about 18 °C (Annila 1969). Varying between years, the flight period starts in the end of April or in May and ends in May or June. The start of a second generation has been observed in exceptionally warm years, but may fail to complete before the start of hibernation. Model estimates based on the developmental time of the life stages show that the current climate in SE Norway makes likelihood of a successful 2$^{nd}$ generation low (Lange et al. 2006 ). Thus, the species is therefore univoltine in the large majority of the sites and years in SE Norway (>90% of cases).

**References**

Annila E. 1969. Influence of temperature upon the development and voltinism of *Ips typographus* L. (Coleoptera, Scolytidae). – Ann. Zool. Fennici, 6, 161–208.

Austaraa Ø. et al. 1977. Bivoltism in *Ips typographus* in Norway, and winter mortality in second generation. – Medd. Nor. Inst. Skogforsk, 33, 272–281.

Lange H. et al. 2006. Thresholds in the life cycle of the spruce bark beetle under climate change. – Inter. Complex Syst. 1648.

Skogbrand (www.skogbrand.no)

Worrell R. 1983. Damage by the spruce bark beetle in south Norway 1970–80: a survey, and factors affecting its occurrence. – Medd Norsk Inst Skogforsk, 38, 1–34.