A rare event – an isolated outbreak of the pine-tree lappet moth (*Dendrolimus pini*) in the Stockholm archipelago

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The pine-tree lappet moth, *Dendrolimus pini* (L.), belonging to the family Lasiocampidae has a wide distribution in Eurasia. In Sweden it is normally found up to 61°N and normally occurs at low densities. In central Europe there have been several reports of outbreaks in historical time. In Sweden the last known outbreak before the one reported here was in 1938-40 in Värmland. In this paper we report a recent severe *D. pini* outbreak that was discovered in 2012 on the small island Furuskär in the Stockholm archipelago. The distribution of the damage on the island as well as a detailed inventory of larvae and pupae on individual trees is presented. Several photographs are presented to illustrate the damage. In the paper we formulate and try to answer several questions that arose as a natural consequence of this rare event: Why was this particular island hit? What are the causes behind the outbreak? What will happen to the trees and the vegetation on the island? Will the outbreak continue? Will the outbreak spread?

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A severe outbreak of the pine-tree lappet, *Dendrolimus pini* (L.), was unexpectedly discovered in 2012 on a small, fairly isolated island in the Stockholm archipelago (Fig. 1). This is the first outbreak of *D. pini* recorded in Sweden during the last 70 years, although the species occurs in moderate densities in conifer forests over southern and central Sweden. In this paper we present data and pictures documenting this rare outbreak after briefly presenting the basic biology of the species and its outbreak history in Europe. In addition, we raise and try to answer questions that naturally arose as a consequence of this rare event.

Dendrolimus pini belongs to the lappet moth family, Lasiocampidae (Lepidoptera). The species is distributed throughout Eurasia into Siberia. In Sweden it normally occurs at low densities up to 61°N. It is a well known outbreak species that may cause severe damage and substantial tree death to conifers, particularly Scots pine (*Pinus sylvestris*). *Dendrolimus pini* prefers open areas with pine, with warm and sandy soil, but also commonly occurs on ridges and precipices with old pine forest. The preferred sites are characterized by low precipitation. The female lays about 150-350 eggs on branches and stems in July. The eggs hatch after 2-3 weeks. The larvae develop

Figure 1. Almost all pine trees were completely defoliated by pine-tree lappet moth larvae.

Nästan alla tallar på Furuskär var helt kalätna av tallspinnarens larver. I brist på tallbarr har larverna ätit barren på de få granar som växer på ön. Detta är ett tydligt tecken på födobrist och är ofta en anledning till att insektsutbrott upphör. Foto: Martin Schroeder.

through six instars and development may be completed after one or two hibernations. In October the half-grown larvae descend and crawl into the soil to find an overwintering site. After hibernation, the larvae feed during the summer and may owervinter a second time. These larvae will spin cocoons and pupate in May or early June. In southern Sweden the larvae develop into adults already in the second summer and emerge in July. The moths emerge after about 20 days. One larva can consume around 600-1000 needles during its life (Hydén 2006).

Dendrolimus pini is a well known pest species with regular outbreaks in many areas dominated by Scots pine forests in Eastern and central Europe. Some figures may illustrate why this species is considered to be one of the most severe defoliating insects in pine forests. In Germany as many as 77 outbreaks have been recorded between 1700 and 1929 (Ritter 1929). In 1869-1872 more than 1 750 000 hectares were defoliated resulting in substantial tree mortality (Schwenke 1978). In Poland several outbreaks are documented since 1791, and between 1946-1995 more than 200 000 hectares were treated firstly with glue rings attached to the stem, later with DDT and after that with pyrethroids, hormone analogs and Bt (*Bacillus thuringiensis*) to control this insect (Sierpiñska 1998).

In Scandinavia very few large outbreaks are known. In Norway, about 5 000 hectares (Schöyen 1880) were defoliated in 1812-1816. In 1902, a maller outbreak occurred on 600 ha in the same area (Myhrwoldt 1902, Mewes 1903).

In Sweden, only one documented outbreak gives information about the area defoliated. In 1938-40, an area of 700 ha dominated by Scots pine at Sörmon outside Karlstad in west central Sweden was defoliated (Forsslund 1940). After that there are no recorded outbreaks in Sweden.

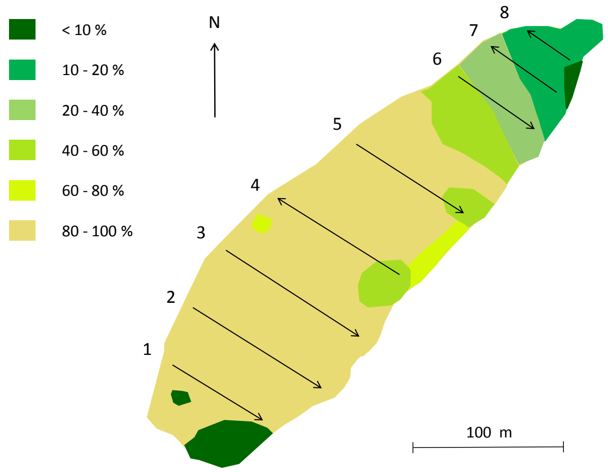

Figure 2. Map of the island Furuskär describing the level of defoliation by larvae of the pine-tree lappet moth (*Dendrolimus pini*) as estimated through visual inspection on 18 September 2012. The arrows accompanied by numbers indicate the placement of transects along which larval and pupal densities were estimated. The actual data are presented in an Appendix 1.

Karta över ön Furuskär som beskriver graden av defoliering orsakad av tallspinnarens (*Dendrolimus pini*) larver uppskattat genom okulär besiktning från marken den 18 september 2012. Pilarna med vidhängande nummer visar placering och riktning av transekter längs med vilka larv- och pupptätheter uppskattades. Datat presenteras i detalj i Appendix 1.

The outbreak of *D. pini* on the small island (1.5 ha) of Furuskär (N 59° 13.766', E 18° 38.375') in the Stockholm archipelago was first reported in June 29, 2012. The discovery was made by Gunnar Hjertstrand and colleagues during the third round of the yearly inventories of eider (*Somateria mollissima*) from boat in the archipelago (Staav 2012). Already during one of the first two inventories in April 22 or June 5, Hjertstrand *et al*. noted that the forest on Furuskär looked peculiar but they did not go ashore at that time. The island is situated between Ingarö and Nämndö and is fairly isolated (nearest distance to the main island Ingarö 1,7 km, and 0.7 km to nearest small island). The island is dominated by Scots pine. No other islands in the area, several also with Scots pine as dominating tree species, showed any signs of defoliation by *D. pini*.

To experience and learn about the rare outbreak event a group of 18 persons from the Department of Ecology at SLU visited the island on the 18th of September 2012 and collected the data presented here. We used three methods for documenting the outbreak. First, a survey of level of damage was done from the ground by walking over the whole island (one person with experience in estimating levels of defoliation did the inventory; Christer Björkman). The island was then divided into zones and areas with different levels of damage with an accuracy of approximately 10-20 %. Second, the numbers of cocoons (Fig. 3) and larvae were counted on smaller trees (40-360 cm). The trees were selected from eight transects, 6-62 trees per transect (Fig. 2). Third, twelve individual trees were tagged and photographed. The intention was to use the pictures from 2012 and compare them with pictures taken in coming years. Thus, the results generated with this third method are not presented here. In addition, notes were made about the presence and rough densities of general predators such as ants, spiders, small mammals and birds.

Beside the dominating Scots pine there are a few scattered Norway spruce and junipers, as well as some deciduous trees (*Sorbus, Betula, Tilia*) on the island. The Scots pine varies in age from small young trees to large trees with an age of more than 100 years. The ground floor is dominated by mosses, lichens, blueberries and grasses.

The results from the survey of the level of defoliation are presented in Fig. 2. Although the largest parts of the island were heavily defoliated there were areas at the north and south end of the island with almost no defoliation. Data on the population density on small trees based on larval and pupal counts are not analyzed but are presented in the Appendix. The high density of pupae on the island and the fact that the larval period normally is stretched over two years in-

Figure 3. The characteristic cocoons, often placed together in groups on branches and in treetops.

Överallt såg vi de smutsigt gulbruna kokongerna, ofta flera tillsammans på grenar och toppar. Inuti kokongskalet ligger puppan väl skyddad. Foto: Åke Lindelöw.

dicates that there must have been a high density of small larvae already in 2011 on the island. However, the defoliation caused by these small larvae was probably not very conspicuous and may explain why the outbreak stayed undetected until 2012.

A considerable number of dead *D. pini* larvae were found hanging in the trees, covered with white cocoons made by a larval parasitoid of the braconid subfamily Microgastrinae (Fig. 5). Most likely the parasitoid species was *Protapanteles liparidis* (Bouche), which has previously been reported parasitizing *D. pini* in the province of Uppland, and is generally considered an important natural enemy of *D. pini* (Adolfsson 1984). From several eggs of *D. pini* that were collected on the island a parasitoid emerged, probably *Telenomus tetratomus* (Thomson) (Hym.: Platygastridae). *Telenomus tetratomus* was infrequent in the survey by Adolfsson (1984); however at one heath pine forest site in the province of Uppland about 50 % of the eggs were parasitized by this species. Other observations of natural enemies on the island included two larger ant hills (*Formica rufa/polyctena*) that were active, a diversity of spider species in relatively high densities, a high density of holes in the ground indicating a high small mammal activity, several observations of small mammal individuals and several (3-6) cuckoo *Cuculus canorus* individuals.

Several obvious questions arise as a consequence of this unique outbreak. Why was this particular island hit? What are the causes behind the outbreak? What will happen to the trees and the vegetation on the island? Will the outbreak continue? Will the outbreak spread? We will elaborate on some of these questions below but would first like to clearly stress the difficulty in making any kind of firm conclusions based on what has happened on one single island.

Concerning the first two questions about why this island and the possible causes, the *D. pini* outbreak on Furuskär is only one of (too) many examples where we have no information of what the situation was before the outbreak. The scientific literature is full of examples describing the situation at the peak and end of outbreaks. Also the mechanisms involved in the decline of an outbreak are in many cases well understood. What triggers an outbreak at a certain place at a certain time is in most cases a mystery. There are a lot of hypotheses but due to lack of hard data most hypotheses are still untested. The hypoth-

Figure 4. The PhD students Simon Kärvemo and Vítězslav Maňák watch the defoliation.

Doktoranderna Simon Kärvemo och Vítězslav Maňák tittar på kalätningen och funderar på vilka faktorer som orsakat utbrottet. Ett för tallspinnaren gynnsamt samspel mellan väderlek, naturliga fiender, sjukdomar och födans kvalitet i kombination med slumpen leder till massförökning och att populationen exploderar. Foto: Åke Lindelöw.

eses may be divided into abiotic and biotic. The biotic ones are often divided into bottom-up (via the host plant) and top-down (via natural enemies) when it comes to possible mechanisms. In most cases people seem to believe that there is a combination of factors that trigger an outbreak.

According to the literature (Schwenke 1978) outbreaks of *D. pini* are always related to unusually dry and hot summers. A warm winter, cold weather in May-July combined with a lot of rain in July-August is suggested to trigger population crashes along with food depletion, natural enemies and diseases. The weather in the area of Sweden where Furuskär is situated was characterized by warmer temperatures than average in May-July 2011 but average precipitation in July-August 2011. The most extreme weather events preceding the outbreak were very high temperatures in July 2010 and April 2011. It may be worth noting that the average yearly temperature has been exceptionally high since the late 1980s in the area. Whether a long period of warm weather can lead to a build-up of *D. pini* population is unclear.

In the case of the outbreak on Furuskär one possible explanation to why this island was hit could be related to the vegetation. Furuskär has, compared to most other islands in the Stockholm archipelago, exceptionally homogenous vegetation with a few plants dominating the ground cover. The main plants are *Vaccinium* shrubs (Sw: blåbär och lingon), mosses and grasses. The low variability in vegetation is, in turn, at least partly a consequence of the topography of the island with steep shores and a lack of meadow-like habitats. On other islands with a less steep topography there are often parts with a diversity of herbaceous plants along the shore line. The herbs are host plants for a diversity of moths and butterflies which, function as alternative hosts for parasitoids. Low abundances of butterflies and moths may thus lead to a low abundance of parasitoids. This in turn could have led to low enemy pressure on *D. pini*, which in combination with favorable weather may have triggered the outbreak.

The relatively high abundance of generalist predators (ants, spiders and small mammals) indicate that the impact of generalist natural enemies is not enough to hinder an outbreak. The hairy larvae may be unpalatable or not preferred by predators. The habit of *D. pini* to spin their loose cocoons up in the trees make them inaccessible to small mammals that are known to have the potential to control other pine defoliators such as the pine sawfly *Neodiprion sertifer*

Figure 5. The larva of the pine-tree lappet moth with its characteristic blue spots.

Tallspinnarens larv med de karakteristiska blå fläckarna. De håriga larverna bör hanteras med viss försiktighet för att inte håren ska tränga in i huden och förorsaka irritation och allergiska reaktioner. Handskar på! Foto: Vítězslav Maňák.

Figure 6. Many of the dead larvae were covered by parasitoid cocoons *(*Braconidae, Microgastrinae*).*

Många döda larver var täckta av parasitstekelkokonger (Braconidae, Microgastrinae). Naturliga fiender som dessa utgör en pusselbit i tallspinnarens populationsdynamik. De förökar sig också och parasiterar en allt större del av larverna under ett utbrott. Foto: Martin Schroeder.

(Hanski & Parviainen 1985). An interesting observation when we visited the island was the high density of migrating cuckoos that are known to prefer hairy insect larvae. Although the impact of birds on insect populations may be relatively large it is difficult to imagine that low predation by birds would have anything to do with triggering the *D. pini* outbreak on Fururskär.

The third question about what will happen to the trees will be more thoroughly studied in the coming years when the island is revisited. Individual trees were marked and photographed on 2012-09-18. The general impression was that few of the most severely damaged trees had any fresh buds. Thus, high tree mortality is expected. How this will affect the vegetation on the island will have to be studied in detail. Many of the larger trees will most probably stand for decades if they are dead and left alone.

The fourth question about the continuation of the outbreak is difficult to answer. However, the low density of needles for the larvae to feed on implies that they soon will experience food shortage. Thus, the outbreak is not likely to continue for more than a year on Furuskär.

The fifth question concerning the possible spread of the outbreak is even more difficult to answer. According to sources from the 1800s referred to in Schwerdtfeger (1936) female moths are able to fly to nearby pine stands not yet defoliated. Unmated females are according to the same source not prone to disperse. In most insect and moth species there is a small proportion of individuals that disperse longer distances (Zera & Denno 1997). Based on this information it is not possible to make any more precise predictions about the possible spread of the outbreak from Furuskär. However, since the island is fairly isolated – it is more than 700 m to the nearest larger island or mainland – and the insect probably not a strong disperser it seems unlikely that the outbreak on Furuskär will function as a source for a larger outbreak. The nearest other island is Sandskär situated NE of Furuskär. Since the predominant wind direction is SW it would be wise to keep an eye on the situation on Sandskär with respect to *D. pini* defoliation the coming years.

To conclude, this short note is not intended to give any conclusive answers to the causes behind and the possible consequences of the *Dendrolimus pini* outbreak on Furuskär 2012 but merely serve as a presentation of an interesting event and a documentation that could be used by anyone in the future as a point of reference.

Figure 7. On the 18th of September there were still a few adult moths.

Den 18 september sågs fortfarande en och annan fjäril. I det mulna gråvädret satt de alldeles stilla. Flygtiden är normalt juni-augusti. Foto: Vítězslav Maňák.

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Svensk sammanfattning

Ett kraftigt utbrott av tallspinare, *Dendrolimus pini* (L.), upptäcktes oväntat 2012 på den lilla, relativt isolerade ön Furuskär i Stockholms skärgård. Detta är det första dokumenterade utbrottet av tallspinnare i Sverige de senaste 60 åren trots att arten förekommer i låga tätheter i barrskogar i hela södra och mellersta Sverige och har betydligt mer frekventa utbrott i kontinentala Europa. I denna uppsats presenterar vi data och fotografier som dokumenterar denna ovanliga händelse och ger även en kort presentation av artens biologi och utbrottshistoria i Europa. Vi tar även upp och försöker besvara frågor som är naturliga att ställa sig i samband med detta: (1) Varför blev det utbrott på just denna ö? (2) Vad orsakade utbrottet? Ett möjligt svar på dessa frågor är den uppenbart låga diversiteten av växter på Furuskär jämfört med andra öar som kan leda till låg diversitet och täthet av växtätande insekter som i sin tur kan leda till låg diversitet och täthet av naturliga fiender, särskilt parasitoider. (3) Vad kommer att hända med träden och vegetationen på ön? Sannolikt riskerar många av träden, även de riktigt gamla, att dö. (4) Kommer utbrottet att fortsätta. (5) Kommer utbrottet att sprida sig? Det faktum att det finns relativt lite föda för larverna på ön gör att risken för att utbrottet fortsätter är liten. Att utbrottet skulle sprida sig till andra öar eller fastland är inte heller särskilt troligt på grund av detta samt att ön ligger relativt isolerad.

Appendix I. Data on number of pupae and larvae of different sizes that were alive, dead or parasitized of the pine-tree lappet moth (*Dendrolimus pini*) on individual Scots pine trees, whose height is indicated, along eight transects on the island of Furuskär 18 September 2012. The position of the transects is shown in Fig. 2. The reason for presenting raw data is to provide opportunity for in-depth analyses in follow up surveys.

Data över antal puppor och larver av olika storlek som var levande, döda eller parasiterade av tallspinnare (*Dendrolimus pini*) på enskilda tallar, vars höjd anges, längs åtta transekter på ön Furuskär 18 september 2012. Positionen hos transekterna visas i Fig. 2. Skälet för att presentera dessa rådata är att möjliggöra mer djuplodande analyser i samband med framtida inventeringar.

Transect	Tree height (cm)	Pupae, total	Larvae, big	Larvae, small	Larvae, dead (not parasitized)	Larvae, big, parasitized	Larvae small, parasitized
1	200	2	-	-	-	-	-
1	100	-	-	-	-	-	-
1	100	-	-	-	-	-	-
1	100	3	-	-	-	-	-
1	150	2	-	-	-	-	-
1	150	-	-	1	-	-	-
1	150	-	-	1	-	-	-
1	130	1	-	-	-	-	-
1	200	-	-	-	-	-	-
1	150	2	-	-	-	-	-
1	150	-	-	-	-	-	-
1	110	-	-	-	-	-	-
1	150	1	-	-	-	-	-
1	170	-	-	-	-	-	-
1	210	13	-	-	-	-	-
1	200	-	-	-	1	-	-
1	180	2	-	-	-	-	-
1	150	-	10	1	2	-	-
1	200	7	-	-	1	-	-
1	200	2	-	1	-	-	-
1	200	4	-	-	1	-	-
2	200	7	-	-	-	-	-
2	170	1	2	-	-	-	-
2	100	1	-	-	-	-	-
2	150	1	-	-	-	-	-
2	220	5	-	-	-	-	-
2	150	2	-	-	-	-	-
2	170	3	-	-	-	-	-
2	130	-	-	-	-	-	-
2	100	-	-	-	-	-	-
2	200	2	1	-	-	-	-
2	180	2	-	-	-	-	-
2	200	3	-	-	1	-	-

Appendix continued

Transect	Tree height (cm)	Pupae, total	Larvae, big	Larvae, small	Larvae, dead (not parasitized)	Larvae, big, parasitized	Larvae small, parasitized
2	100	16	2	-	-	-	-
2	100	14	-	1	-	-	-
2	130	15	9	2	-	-	-
2	150	4	-	-	-	-	-
2	100	9	1	-	-	-	-
2	100	1	-	-	-	-	-
2	200	6	-	-	-	-	-
2	180	6	-	-	-	-	-
2	150	6	-	-	-	-	-
2	180	57	-	-	-	-	-
3	150	-	-	-	-	-	-
3	160	3	-	-	-	-	-
3	150	5	-	-	-	-	-
3	200	4	-	-	-	-	-
3	200	12	5	-	-	-	-
3	150	1	-	-	-	-	-
3	190	15	-	-	1	1	-
3	160	33	-	-	1	1	-
3	150	2	-	-	-	-	-
3	180	7	-	-	-	-	-
4	200	8	1	-	-	-	-
4	120	4	-	-	-	-	-
4	100	-	1	2	-	-	-
4	150	11	-	-	-	-	-
4	220	4	-	-	-	-	1
4	100	9	-	-	-	-	-
4	150	5	-	-	-	-	-
4	170	6	-	-	-	-	-
4	100	11	1	4	-	-	-
4	150	1	-	-	-	-	-
5	150	-	5	1	-	-	-
5	180	4	-	-	-	-	-
5	100	1	-	-	-	-	-
5	60	14	1	-	-	-	-
5	120	3	4	-	-	-	-
5	150	6	6	-	-	1	-
5	150	5	9	-	-	-	-
6	120	1	-	-	-	-	-
6	180	6	1	-	-	-	-

Appendix continued

Transect	Tree height (cm)	Pupae, total	Larvae, big	Larvae, small	Larvae, dead (not parasitized)	Larvae, big, parasitized	Larvae small, parasitized
6	110	-	-	1	-	-	-
6	120	-	1	-	-	2	-
6	150	1	5	13	-	1	-
6	100	-	-	8	-	-	-
6	70	2	-	3	-	-	-
6	80	-	-	-	-	-	-
6	80	-	1	-	-	-	-
6	120	1	3	10	-	-	-
7	100	1	-	7	-	-	-
7	100	1	2	-	-	1	-
7	100	1	1	-	-	-	-
7	210	2	3	7	-	-	-
7	100	2	-	1	-	1	-
7	60	-	1	-	-	-	-
7	50	1	-	-	-	-	-
7	40	-	3	1	-	-	-
7	70	2	-	-	-	-	-
7	60	2	-	-	-	-	-
7	50	-	1	2	-	-	-
7	180	8	-	-	-	-	-
7	180	1	-	-	-	-	-
8	130	-	-	-	-	-	-
8	100	-	-	-	-	1	-
8	120	-	-	-	-	-	-
8	120	-	-	-	-	-	-
8	120	-	-	-	-	1	-
8	120	-	-	3	-	-	-
8	120	-	-	1	-	-	1
8	100	-	1	-	-	-	-
8	100	-	-	-	-	-	1
8	50	-	-	-	-	1	-
8	100	-	-	1	-	-	1
8	100	-	-	1	-	-	-
8	120	-	-	-	-	-	-
8	80	-	-	-	-	-	1
8	50	-	-	-	-	1	-
8	50	2	-	-	-	-	-
8	100	2	-	-	-	-	-
8	50	-	1	-	-	1	-