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Climate Change and Shifts in the Distribution of Moth Species in Finland, with a Focus on the Province of Kainuu

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1. Introduction

Distributions and abundances of insect species depend on a variety of factors, but whether we focus on food plants and availability, environmental niches and shelters, predators or parasites, by far the most important limiting factor is climate. Shifts in insect community structure have successfully been correlated with glacial and inter-glacial periods (Coope 1995; Ashworth 1997; Morgan 1997), but have also attracted the attention of researchers concerned with current climate trends. Parmesan (2001) and Forester et al. (2010) examined examples from North America and Europe and emphasized that predictions of responses to a warmer climate must incorporate observations on habitat loss or alteration, land management and dispersal abilities of the species in question.

For the United Kingdom, Hill et al. (2001) have summarized data on changes in the distribution of specifically three butterfly species (*Pararge aegeria, Aphantopus hyperantus*, and *Pyronia tithonus*). These authors report that the three species have been shifting northward since the 1940s and they present maps of simulated butterfly distributions for the period 2070-2099, based on the changes seen since the 1940s. According to that scenario Iceland will see some colonies of these three species in less than a hundred years. Monitoring specifically moth distributions has been less popular (Chen et al. 2009; Park et al. 2009), and especially microlepidopteran species have not received the attention they deserve, so that few detailed observations on their distribution pattrerns, covering longer periods, exist.

Söderman (1994) reports that a programme to monitor moth abundance and species composition has been developed and run as a Nordic project since the middle of the 1990´s. At the moment the following countries are involved in this Moth Monitoring Scheme (MMS): Denmark, Finland, Iceland, Sweden, (at regional level), Estonia, Latvia, Lithuania and Russia (restricted to Karelia, the St.Petersburg region, and the Pskov region). The methods recommended and explained further below are meant to be used by all participants of the project. To our disappointment, however, moth monitoring in the other Nordic countries has not progressed at the same level that it has in Finland, which is why we focus on the Finnish data in this article.

Collecting butterflies and moths has a long tradition in Finland and the basic knowledge of the distribution of the Finnish macrolepidopteran species is rather good, especially thanks to the comprehensive works by Kaisila (1962), Mikkola (1979) and Huldén et al. (2000). Systematic, regular monitoring of moths in Finland started in 1993 (Somerma et al 1993) and has involved a network of light traps located all over the country.

The contribution of the Province of Kainuu to that project has been significant (see further below) and has helped us to create a solid base to notice changes in the Finnish moth fauna. In the Kainuu area we have not only carried out some extra collecting, employing methods additional to those used elsewhere in Finland (cf., Material and Methods), but we have also been paying particular attention to the microlepidoptera. Based on the two sets of data (from Finland generally and Kainuu Province in particular), we were able to detect changes in the composition of the moth fauna at local county level as well as the wider, biogeographical region, namely the entire territory of Finland.

1.1 Characteristics of the study area

The biogeographical province of Kainuu lies in the eastern part of Middle Finland (Fig. 1) and includes Lake Oulujärvi and a stretch of the river Oulujoki. The lake basin and smaller rivers are defining characters of the province's two easternmost areas. The middle parts of Kainuu, i.e., Puolanka, Hyrynsalmi and Sotkamo, are rich in hills reaching heights of 200-300 m above sea level. In the vicinity of water there are also many eskers running from northwest to southeast and the most remarkable esker series is one that passes through Sotkamo-Vuokatti- Oulujärvi –Rokua.

The natural surroundings of Kainuu are characterized by numerous bodies of water, wide forest areas, eskers, hills and bogs. The large forests give the area a stamp of pristine wilderness. Over 80% of the land area of Kainuu is covered by forests. In the southwestern and western parts of the province bogs dominate the landscape. Especially large boggy areas occur in the vicinity of Vaala. The total area of Kainuu is 24 456 km^{2}, of which the land area alone amounts to 21 571 km^2. The province borders on the following territories: Karelia borealis in the southeast, Savonia borealis in the south, Ostrobothnia borealis in the west, Kuusamo in the northeast and Russia in the east. The number of human inhabitants is around 85 000 (www.Kainuu.fi).

1.2 The Kainuu moth fauna

The macrolepidopterous fauna of the biogeographical province of Kainuu has been well documented thanks to studies in that area that began in the middle of the 19 th century (Tengström 1869). Additional information, including faunal composition of Kainuu moths, has come from investigations by Aro (1900), Valle (1910), Heikinheimo (1939) and Mikkola (1955). In 1993 Leinonen (1993) gathered together all the information available up to that date and added his own observations. Consequently, information specifically on the marolepidopterous moth fauna of Kainuu has been kept at a high level until the beginning of the last decade of the 20 th century. An updated compilation of the macrolepidoptera for the whole of Finland up to 1997 was published by Huldén et al (2000), also including the then latest available data from the Kainuu area.

Fig. 1. Location of Kainuu biogeographical province in eastern Middle Finland from approximately 64 – 66 degree latitude. 15 mm correspond to ca. 100 km.

On the other hand, there were no published Finland-wide data on the microlepidopterous fauna even though lists of captures or sightings of microlepidopteran species were available from Finland at county level. Basically the most up-to-date work on Finnish microlepidoptera is that by Kyrki (1978), whose study material came from museums and several private collections. At that time 433 microlepidopterous species were known from the Kainuu area alone. Two additions supplemented the earlier publication (Kyrki 1979; Kyrki & Tabell 1984) and even more recent updates were published by Kerppola et al (1995) and Kullberg et al. (2002). Thus, material to compare the present Kainuu microlepidopterous fauna with older compilations does exist, but a thorough investigation into the question of the compositional origins of the microlepidopterous fauna had not been carried out until we started our research in 1987. We have recently published results on the moth fauna of the Friendship Nature Reserve, a joint park between Russia and Finland (Leinonen et al. 1997). The Finnish parts of the park lie near the eastern border of Kainuu province and most of the finds that this report deals with were made by us in the same area and are included in the above mentioned catalogues.

2. Material and methods

2.1 Equipment used and areas visited

One of the largest monitoring exercises in Finland is the Nocturnal Moth Monitoring (NMM) project, which started in 1993 (Somerma et al 1993, Söderman 1994) and still continues (Söderman et al 1994, 1995, 1997, 1999, Nieminen 1996, Leinonen et al 1998a, 1999, 2000, 2003). In this project the numbers of species and individuals of the so-called macrolepidoptera are recorded. Furthermore the distribution of the sexes, number of generations per year and any noteworthy changes have been recorded. From the Kainuu study sites we also have identified and counted the so-called microlepidoptera (Leinonen & Itämies, unpublished data).

For Finland's NMM project, altogether 205 light traps around the country have been in operation for at least one collecting period ever since the project started (Fig. 2). Basic automatic and passive collecting has involved Jalas light-traps (Jalas 1960). The traps were initially equipped with 160 W mixed light lamps and later with 125 W mercury vapour lamps. The traps were emptied once a week and all so-called macrolepidopterous species were identified, counted and sexed. As with some butterflies (e.g., *Pieris napi*: Meyer-Rochow and Järvilehto, 1997) in some species of moths different colour morphs were noticed and recorded. Identifications were made by the members of the Finnish Lepidopterological Society and the data were fed into the Hertta-database and preserved in separate files for each year at the Finnish Environment Institute. At this moment the database includes almost six million records.

The number of traps used over the years has fluctuated (Table 1). There were 5 sites where a trap was in operation every year since 1993 and in the town area of Kajaani one trap was in operation for 21 years between 1984-2005. All light trap material is included into the data of the NMM project. Additionally, bait-trapping has been used extensively in connection with the Oulu-model trap (Fig. 3), according to Laaksonen et al. (2006). More randomly we have also made use of malaise, pheromone and colour traps. During the first years of monitoring the lepidopteran faunas in the Friendship Park area of Kuhmo and Suomussalmi, we used baited traps of the "Jalas type", but later we used the "Oulu-model". The largest bait

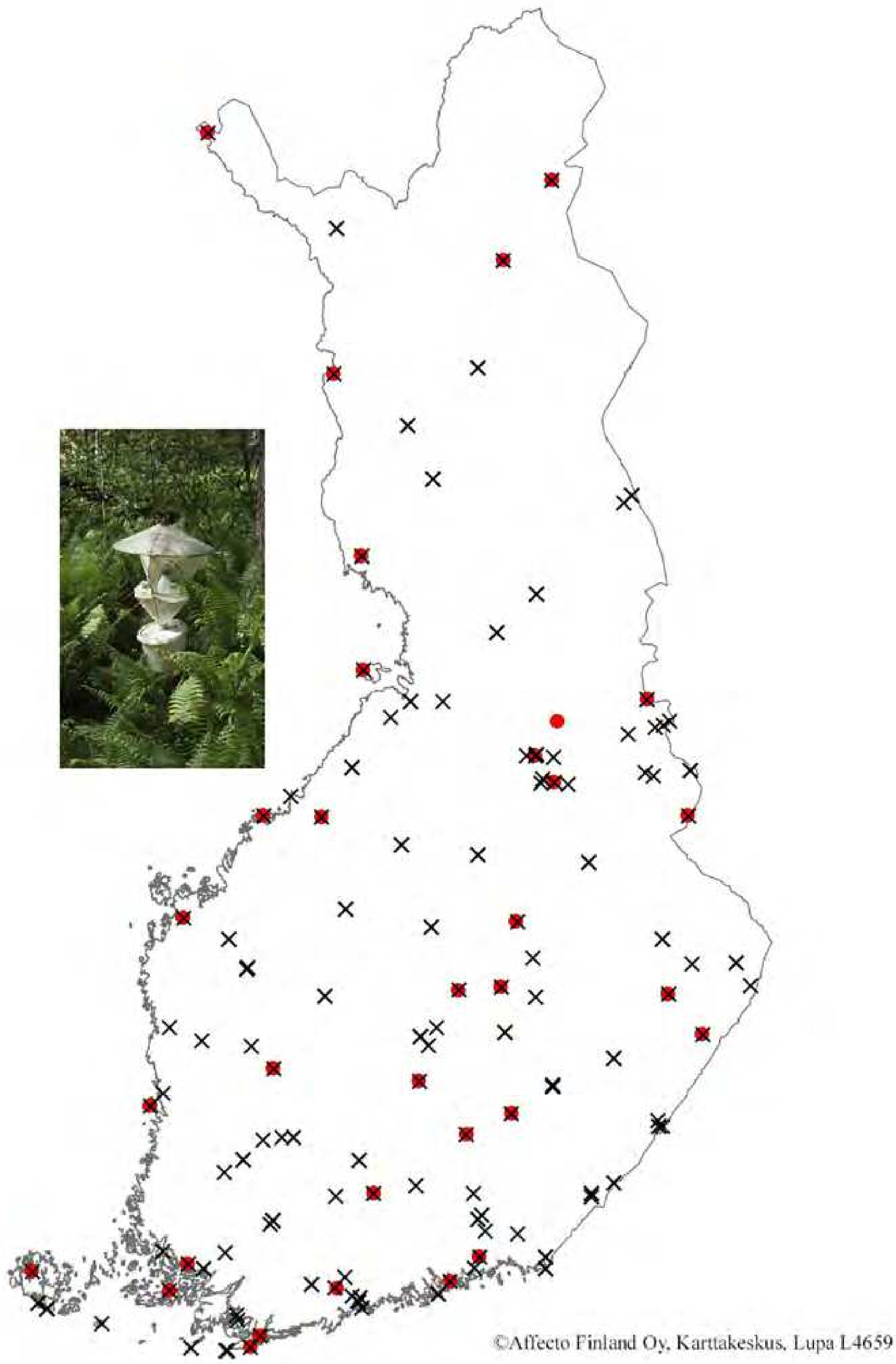

Fig. 2. The light trapping network of the Finnish Nocturnal Moth Monitoring project. Key to symbols: black cross = trap has been in use <15 years; red circle = trap has been in use > 15 years.

Fig. 3. The Oulu-model bait trap (cf. Laaksonen et al. 2006) used in the moth mapping of the Kainuu area.

	light	bait	malaise	pheromone	colour
1987	1				
1990	1				
1991	2	3			
1992	4	20			
1993	12	18			
1994	15	19			
1995	17	29		30	
1996	18	1		17	18
1997	15	31			27
1998	10	5	1	15	18
1999	11	15			23
2000	10	6	1	18	21
2001	10	112		29?	21
2002	10	74		17	18
2003	11	19	4		21
2004	6	1	4	1	18
2005	7	9	5		10
2006	6	2	2		
2007	6	3	3		1
2008	6	2	2	6	2
2009	6	1	2	15	3
2010	6	1	3	15	3

Table 1. List of yearly numbers and types of traps used in the Kainuu area in the years 1987 and 1990-2010.

trapping was carried out in the years 2001-2003, when over one hundred bait traps were used in the joint area of Kainuu and Russian Karelia. This study on the impact of the primeval forest area of Vienan Karelia was carried out to assess the animal populations of old Kainuu forests (including Landscape Ecology of moths in Russian Karelia and the adjacent Finnish province Kainuu), with special attention given to the influence of human activity upon the local moth fauna (Várkonyi & Leinonen 2004).
Our thorough mapping-exercises were based on active searching, either by visiting new sites or by collecting moths from certain food plants. Emphasis has been on species not previously reported from the Kainuu area.

2.2. Groups of Lepidoptera investigated

We have kept micros (Micropterigidae-Pterophoridae) and macros (Papilionidae-Noctuidae) separate, but the general level of knowledge regarding species in these groups varies from region to region. In Finland there are many people who occupy themselves with macros, but much fewer enthusiasts, perhaps one tenth, involve themselves with micros. The first task, therefore, was to identify the new arrivals to the region. We use two different terms and distinguish: a) new provincial finds (npf), which means a species occurring in the province of Kainuu, but not having been reported earlier from there, and b) species that can be considered new to the region and therefore represent new arrivals (nar). Judgments on what is and is not a new provincial find or a new arrival are based largely on published reports.
The interpretation of what constitutes a new arrival is dependent on our experience and also on reports of events from other provinces of Finland. In many cases identification was not at all difficult, but there were also controversial cases. The first difficulty stems from the huge yearly fluctuations of moth catches, obviously increasingly pronounced as we move further northwards (see e.g., Marttila 1992, Itämies & Pulliainen 2006). We had to examine data covering periods of five to six years in order to obtain a basic idea of the moth fauna in the study area. However, there were some rather clear cases that could immediately be recognized as new arrivals even during the first two years of study, based on our own experience and the information available from numerous publications and catalogues.

2.3 Additional information

Another problem presented the group of species that was retrieved through active searching. We could not be absolutely certain, if a species collected from the Kainuu area had already become established there or represented a recent and fleeting visitor. Problematic species such as these were routinely left out of the group of new arrivals. We can illuminate these problems by some exemplary species. *Notocelia roborana* was not included as a new arrival, although it was not recorded from Kainuu until 2003. It depends on rose bushes, which means that it is more or less bound to cultural surroundings. There is of course a small possibility that it had arrived recently, but events in other counties do not support this idea. It seems to have been overlooked earlier. Rather similar is the case with *Eucosma hohenwartiana*, first reported in 2002. It is an inhabitant of meadows with *Centaurea* species, which in the Kainuu area are extremely rare. The species seems to expand its range, but we left it out of the group of arrivals, because we believe it must have been overlooked earlier.
In order to establish which kinds of species are indeed invading the northern regions of Finland, we grouped species together according to their habitat preferences (see Appendix).

One species could be listed in more than one habitat, if it was able to exist in several biotopes. This means that the total number of species deemed to represent new arrivals, may be somewhat larger than the real number. We therefore assigned "habitat points" to each species. The habitat classification used was as follows: df = deciduous forest; cf= coniferous forest; c= cultural surroundings, i.e. habitats made by man like yards, gardens, parks etc.; m= meadows; dm =dry meadows; r= ruderal areas; b= bogs, fens and marshes; dh= extremely sun exposed heaths and slopes; bu= bushes, all kind of border areas of forests, meadows and roads with rich deciduous bushes; cc= clear cuts.

In addition, two columns were added that provided information on the type of targeted searching, i.e., d = actively searched, and ph=collected by pheromones. In the last column the number of migratory moth species is given. These were added to the arrivals, but they were not assigned to any of the habitat groups. Finally, in our comprehensive table (Appendix) we have used a three-step-scale to evaluate the present status of the arrivals as to their success in settling in the Kainuu province.

Another aspect for which we wanted to obtain information, was related to the arrivals' hibernation characteristics. Towards this end, groupings of macrolepidoptera were based on the results of Mikkola & Jalas (1977, 1979), and Mikkola et al. (1985, 1989) while those involving microlepidoptera were based on Schütze (1931), Emmet (1979) and Svensson (1993). Nomenclature follows that of Kullberg et al. (2002).

3. Results

During the years 1987-2010 altogether 258 species of moths were determined as new, i.e., not recorded until then from the biogeographical province of Kainuu. Of these species 187 were representatives of micro and 71 of macrolepidoptera. Altogether 38 species were the results of targeted searching and, as could be expected, this pattern of new records occurred at the beginning of our study period (Fig. 4) and on the other hand most of them (37) were microlepidoptera. It should not surprise that with the kind of massive collecting that took place at that time, increasing numbers of new provincial finds happened mainly during the first few years.

When we arbitrarily divide the series into three periods (1987-95, 1996-2000 and 2001-2010), more interesting features can be revealed. The huge peak of new species is still obvious for the first period (108 species), but one also notices that the last period, especially the first seven years of it, were almost equally profitable in that 97 new species were recorded over that time. There seems to be some kind of collapse during the last three years of the third period, but only future observations will be able to tell us whether this signifies a permanent feature or has to be regarded as a temporary event. In total 77 species were identified as new arrivals and the greatest bulk of these arrived during the last period (Fig. 4).

3.1 Habitat distribution

We distinguished 11 habitat groups to which the species could be assigned (see Material and Methods). Most species were found to belong to the deciduous forest group. When we added to that group species living in various bushy habitats, we see that together they reach 123 points. Meadows and dry meadows follow with 98 points. A rather large number of species also occurred in cultural surroundings (49) and on ruderates (22). Very few new species, however, were collected from bogs (14) and from sun-exposed dry heaths (7).

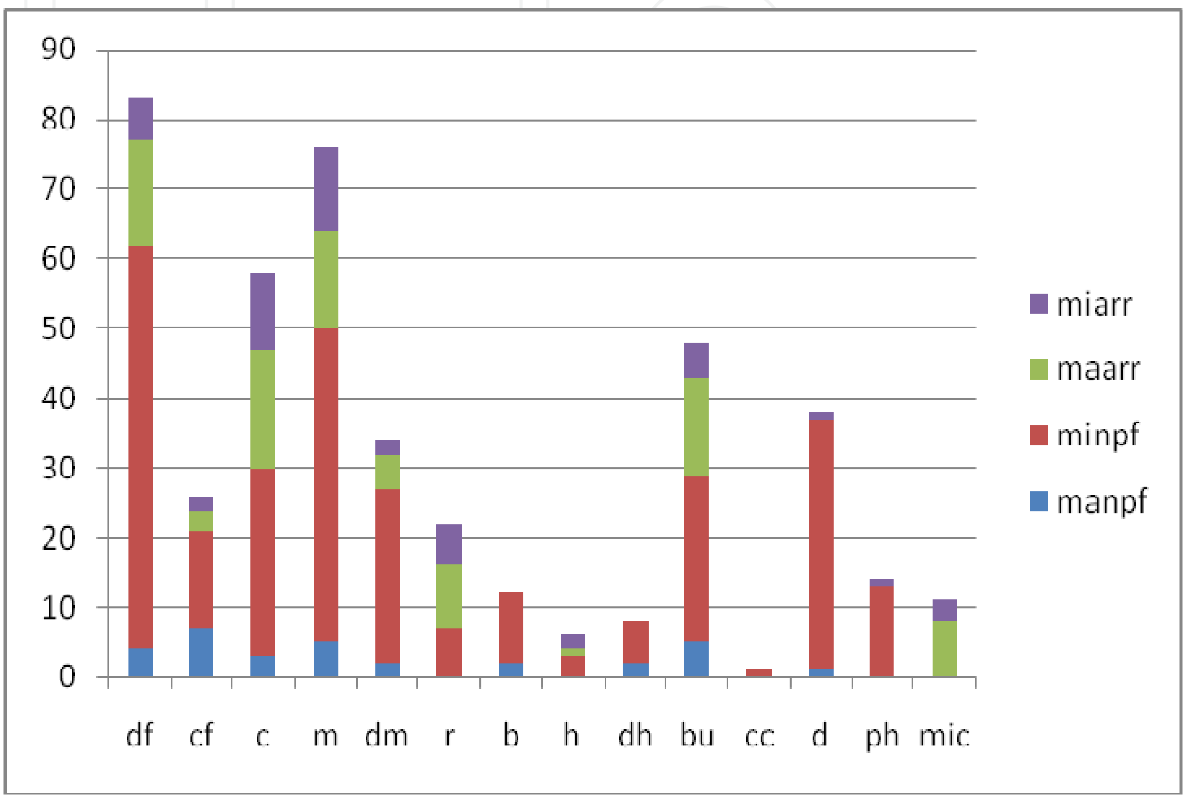

Fig. 4. Habitat distribution of new provincial finds (npf) and new arrivals (arr) of microlepidoptera (mi) and macrolepidoptera (ma) in the province of Kainuu for the years 1987 and 1990-2010 combined. For abbreviations of habitats on the abscissa see Material and Methods. The ordinate shows the number of species.

When we inspect more closely the habitat distribution of the arrivals versus other new provincial finds, we can extract some features from the material (Fig. 5). Species living in man-made surroundings (c and r) seem to be most actively expanding into the Kainuu region. Meadow habitats are also well inhabited by new arrivals, but the proportion of deciduous forest species, for instance, is much lower than in other new finds. Bogs and dry heaths did not contain any new arrivals, although other new finds were present in these habitats. Through active searching we could hardly find any newcomers, but species hitherto overlooked were readily discovered with this kind of planned searching. A similar result was obtained when pheromone-traps were used. However, it can be expected that if we had kept these traps year after year in the same place, we should have been able to show some newcomers also by this method, but this was unfortunately not done.

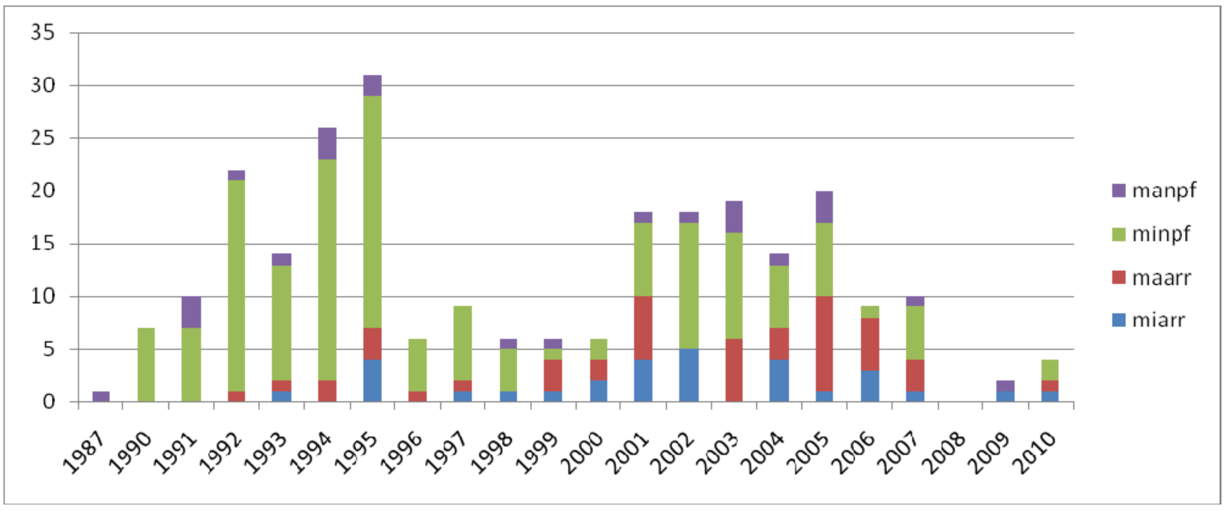

Fig. 5. Yearly catch of new provincial finds (npf) and new arrivals (arr) of microlepidoptera (mi) and macrolepidoptera (ma) in the biogeographical province of Kainuu for the years 1987 and 1990-2010 combined. The ordinate shows number of species; the abscissa depicts the year of monitoring.

3.2 Hibernation phases

Hibernation as larvae was most common amongst all of the newcomers (Fig. 6) irrespective as to whether we singled out micro and macrolepidoptera . Among the macrolepidopterous species, however, there were also many that hibernated in the egg stage and also wintering over as pupae was not exactly rare either. Of the new arrival microlepidopteran species, three were hibernating as imagines, but none of the new arrival macros were in the group of adult overwinterers. The hibernation phases of the latter were rather evenly distributed between egg, larva and pupa, but for the microlepidopteran new arrival species larval hibernation was the rule, although egg hibernators were moderately represented as well.

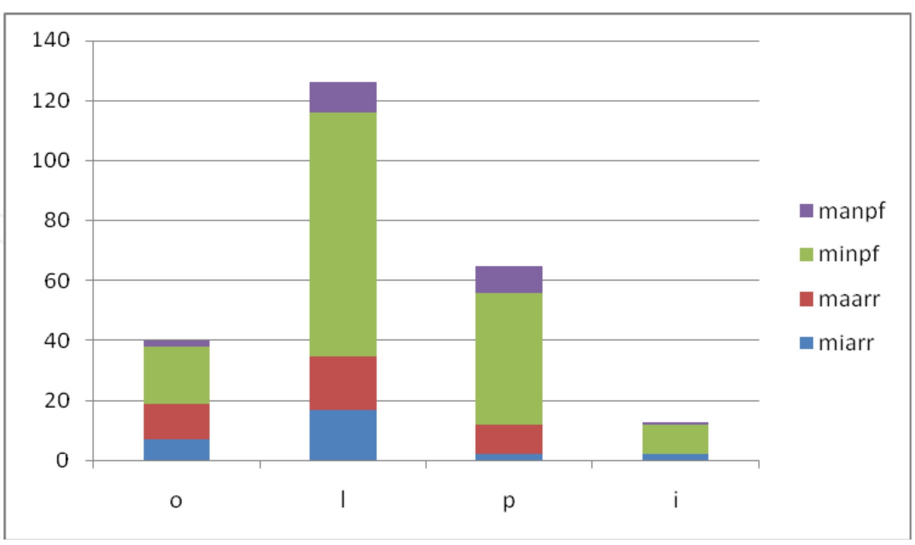

Fig. 6. Hibernating phases of new provincial finds and new arrivals of moths in the Kainuu area, based on data from 1987 and 1990-2010 combined. Explanation of symbols on the abscissa: o = ovum; l = larva; p = pupa; i = imago. The ordinate shows number of species; npf = new provincial find; arr = new arrival; mi = microlepidoptera; ma = macrolepidoptera. The ordinate shows number of species.

3.3 Settling down and becoming established

None of the eleven migratory species appear to have become regulars in the area, although some of them were collected in more than just one year, like, for example, *Agrius convolvuli* (Fig. 7). Settlement history of other newcomers has varied greatly. Many of them were collected only once, but some have expanded their range considerably. We can name as the most successful newcomers *Gracillaria syringella*, *Oncocera semirubella*, *Cryptocala chardinyi*, *Araschnia levana* and *Argynnis paphia*. To date altogether 17 new arrivals seem to have more or less successfully colonised the Kainuu area and become established there (Appendix).

Fig. 7. *Agrius convolvuli*, a typical migratory hawk moth reported a couple of times also from the Kainuu area during the last few years. Photo Reima Leinonen.

3.3.1 Observed changes in the moth fauna Finland-wide

The available general information on the Finnish lepidopterous fauna stems from the large network of amateurs and their observations and from professional research efforts at various Finnish universities. The Finnish Lepidopterological Society has over a thousand members, which gives a good idea about the breadth of the hobby of butterfly and moth collectors in Finland with its 5.4 million inhabitants. Moreover, children learn already at school facts about Finnish butterflies and moths (Meyer-Rochow 2008). During the last few years increasingly more attention has been paid to changes in the natural surroundings. One of the largest monitoring exercises in Finland is the Nocturnal Moth Monitoring project (abbreviated NMM), which started in 1993 (Somerma et al 1993, Söderman 1994) and some conclusions presented in this chapter are based on that material, representing a short review of the results of 17 years of monitoring. Year-by-year summaries of this project have been presented quite regularly (Söderman et al 1994, 1995, 1997, 1999, Nieminen 1996, Leinonen et al 1998a,1999, 2000, 2003) and specific surveys based on those many years of data have also been presented at various seminars, in conference abstracts and review articles like the most recent one by Leinonen et al (2011).
For collecting of proper material see chapter 2.3. above.

3.3.2 Observed changes in the moth fauna of northern Finland

In the results of the NMM we find evidence in support of the northward spread of several species, suggesting that this northward expansion could be the result of an increasingly warmer climate. Numerous new arrivals have been recorded from Finland and many southern species have expanded their ranges northward. Examples of southern species spreading into northern regions are the following ones: *Allophyes oxyacanthae* (Fig. 8), *Protodeltote pygarga* and *Cosmia trapezina*. *Cryptocala chardinyi* is one of the most illuminating species when it comes to the rapid expansion of distribution area in Finland (Fig. 9).

The opposite phenomenon to the above mentioned scenario is that there are indications that certain species have started to withdraw from southern Finland or at least their population sizes have been dwindling. We can mention, for example, the following species: *Entephria caesiata*, *Xanthorhoe annotinata* and *Dasypolia temple*. Maps based on the situation at the beginning of NMM and after fifteen years show the obvious trend happening in the area of this moth (Fig. 10).

Fig. 8. *Allophyes oxyacanthae*, one of numerous moth species presently extending its range northward in Finland. Photo Reima Leinonen.

The structure of the species composition has also undergone change. Populations of species earlier known to be abundant have visibly decreased. Species compositions have started to resemble more and more those typical of Central Europe, where the number of species is high but the numbers of individuals are relatively low. At the same time the populations of some species have increased dramatically and we can talk about pest risks. Here we can take *Lymantria monacha* as an example of a species which may in the near future be so abundant as to be able to cause forest disasters even in Finland like it has done in Central Europe.

In the northernmost part of Finland, in Lapland, the geometrid moth *Epirrita autumnata* (Fig. 11) is known to have mass outbreaks with intervals of approximately ten years, when it severely affects mountain birch forests. The trees will stand a one-year-disaster, but if the catastrophe goes on for several years, the trees are likely to die. The eggs of *E. autumnata* are

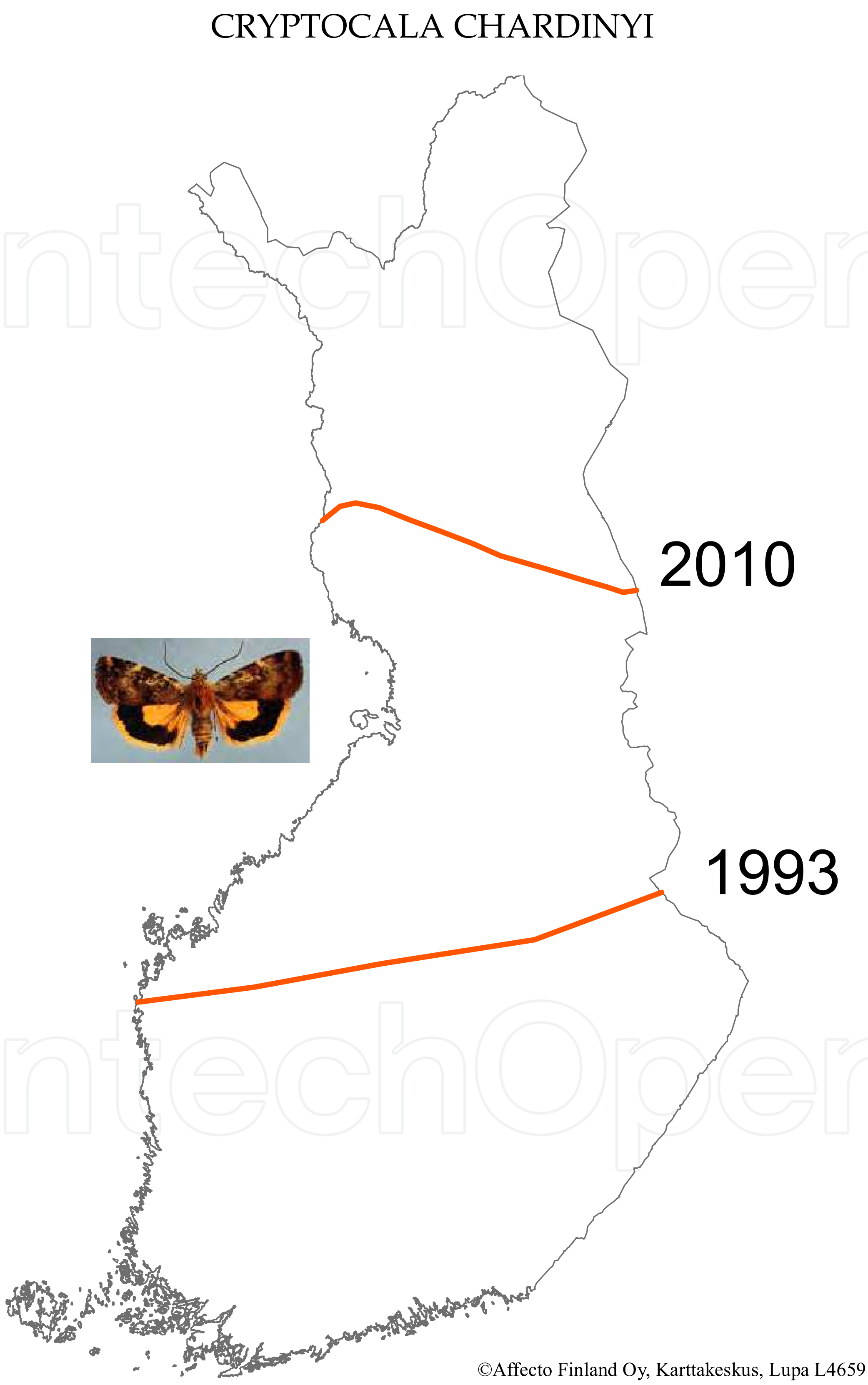

Fig. 9. Map showing the increase in the distribution area of *Cryptocala chardinyi* in Finland based on data from the Finnish Nocturnal Moth Monitoring project.

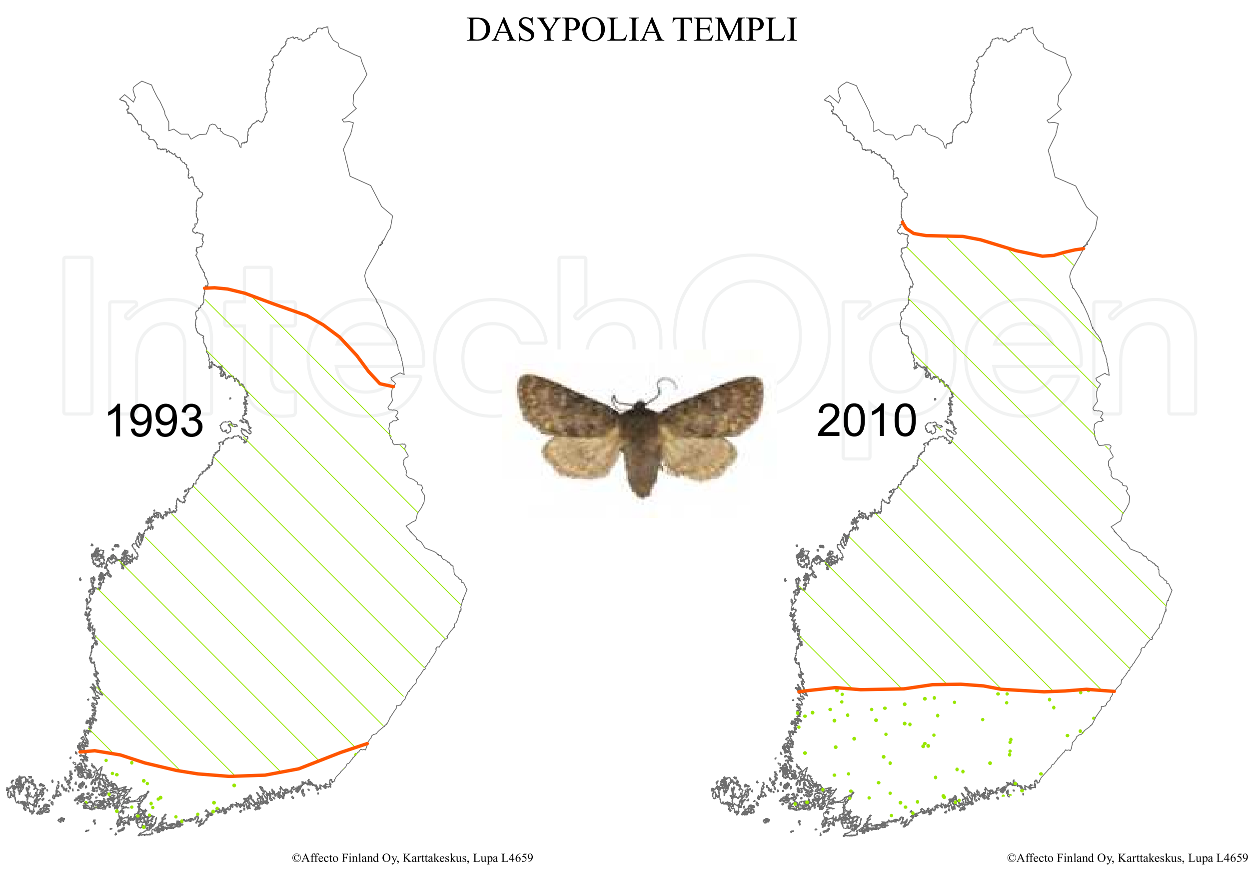

Fig. 10. Maps showing the northward withdrawal of *Dasypolia templi* in Finland based on data from the Finnish Nocturnal Moth Monitoring project.

Fig. 11. *Epirrita autumnata*, a geometrid moth which in northernmost Finland has massive outbreaks in mountain birch forests (*Betula pubescens*) and which in the future may occur more often, if the winters get milder due to global climate warming.

vulnerable to very low temperatures, i.e. if they encounter temperatures of -40°C, all but approximately 2 % will die. However, if temperatures stay above -35°C, then up to 96% of the eggs will survive. Mild winters due to global climate warming may thus promote disasters in northern mountain birch forests.

One of the clearest indications of climate warming in our NMM data is the increase of second annual generations. This has been observed in a growing number of species and in more and more northern localities. *Gymnoscelis rufifasciata* is an extreme example of this phenomenon, because it has nowadays even a third generation quite regularly in some areas of southern Finland (Fig. 12). Having second or even third generations in regions as far north as Lapland or northern Finland generally is not necessarily beneficial to the species, for it can be a risk to the population. If the species does not get ready for hibernation, that part of population will be lost and in the long run the species may even become endangered.

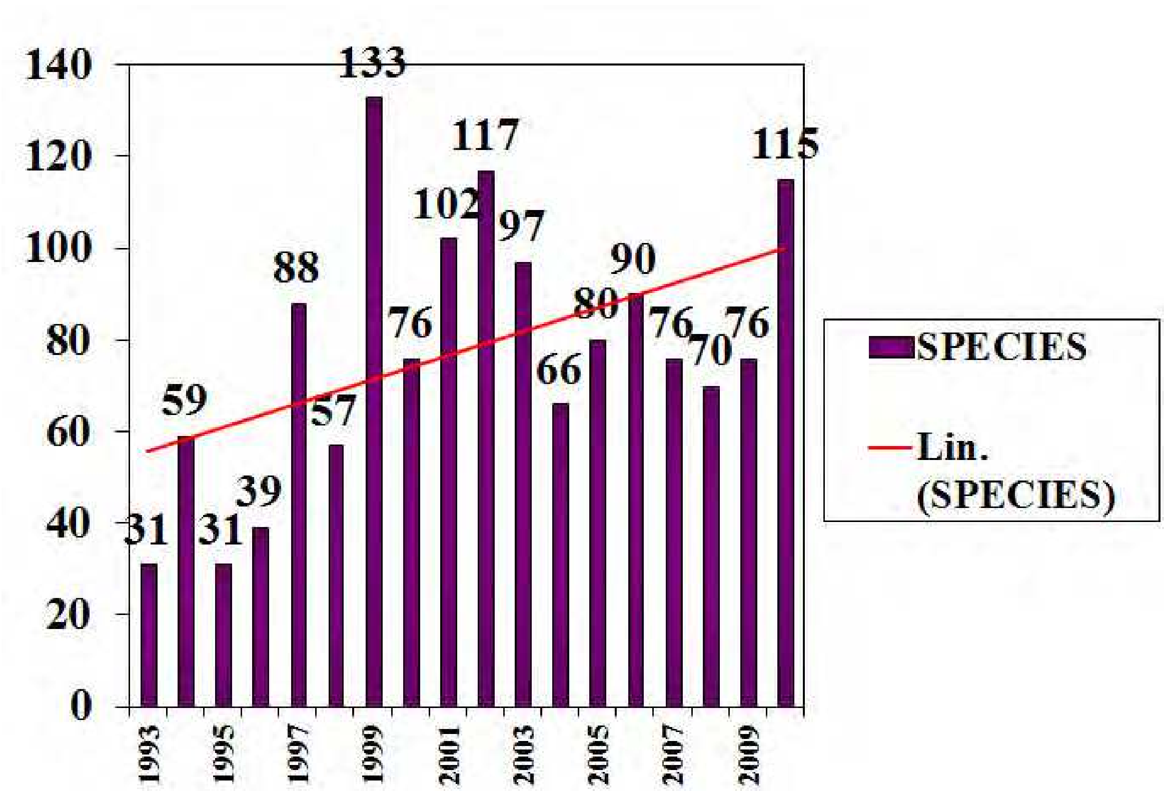

Fig. 12. The number of species with second generations per annum has steadily been increasing with *Gymnoscelis rufifasciata*, a geometrid moth representing the ultimate example of an increase in annual generations in Finland to two or even three generations during the last few years, based on the material of the Finnish Nocturnal Moth Monitoring project.

3.4 Alpha-diversities

As to the diversity index, we used the data of the FMM and calculated the so called alpha-index. At the beginning of monitoring activities in 1993 the value was a little above 60, while at the same time for Lithuania it was, for instance, close to one hundred. At present the alpha-indices are close to a hundred in certain parts of southern Finland. This reflects the increase of species numbers and that the observed specimen numbers are closer to each other, i.e. the huge mass occurrences of individual species are lacking. In northern Finland the alpha-values stay still low mainly due to two reasons. The effectiveness of light traps is weak around midsummer in Lapland due to the continuous summer daylight and the species numbers are originally low to start with. Secondly, in the north we still have species that exhibit quite regular mass outbreaks, thus keeping alpha-values low.

4. Discussion

It is not unusual to find that insect populations peak and decline in cycles and that the cycles can have periodicities varying from one to many years. This is one major difficulty in trying to draw conclusions on insect abundances in relation to climate change (Meyer-Rochow 2008). Therefore, it is essential that one has data on population densities and species compositions over long time spans for a defined geographic region; another equally important requirement is that one has reliable weather records over many years for the region in question. Our investigation meet both of these criteria.

The longest continuous set of Finnish temperature data exists from the area of Helsinki, Kaisaniemi, from where we have almost two hundred years of recordings. Statistics preserved at the Finnish Meteorological Institute show that the average daily temperatures and especially the lowest daily temperatures have been rising most clearly during the last decade. This means that nighttime temperatures have risen, thus enabling species demanding higher minimum temperatures to spread and survive even in the northern regions of Finland. At the same time the winters have become shorter and milder. On the other hand, increasing summer rains, observed in the last few years, could present a problem for some species.

The results of the Finnish NMM project demonstrate convincingly that there has been a dramatic increase over the last ten years in the number of new records for species of moths in Finland generally and the biogeographical province of Kainuu in particular. This is not, however, a new phenomenon, for Kaisila (1962) had already shown how the rising average summer temperature around the turning point of the 1940s, had caused many species in Finland to expand their ranges northward. He named several species as expansive ones. Yet, many of the species Kaisila (1962) had identified as those with northward expanding ranges, later withdrew again from their northernmost expanses when cooler summers returned (see for instance Huldén et al. 2000).

The period studied by Kaisila (1962) ended in 1961, but Mikkola (1997) followed up Kaisila’s work and analysed migrations of Lepidoptera until 1996. The overlap of three years with the NMM (which had started in 1993) and the availability of the early NMM data were, thus, a bonus to Mikkola’s investigation. According to Mikkola’s analyses, 30 recent invaders and 40 older expansive species were once again spreading into northern Finland. These basic and important investigations, however, were almost totally lacking information on microlepidoptera, because the general knowledge with regard to the latter was so poor that they had to be left out of the analyses. At province level, however, similar expansion trends in this moth group as compared to the macrolepidoptera were noticed. Since species belonging to the microlepidoptera are frequently very specific with regard to their larval food plants, one could have expected that this would have presented a hindrance to their northward spread and therefore function as a severe obstacle in range expansion.

Yet, our results show that changes in the moth fauna of Finland are not only continuing, but are possibly taking place at a greater pace than ever before. We must, of course, keep in mind that the number of collectors has increased remarkably and that the traps and trapping efforts have become vastly more efficient than what they were some 50 years ago. In spite of that we dare say, however, that the moth fauna, especially in northern Finland, has been undergoing a dramatic change over the last few years.

4.1 Possible reasons of the northward expansion

What could possibly be the cause of this situation? Moths and in particular their larvae depend on live, green plants, some very strictly limited to one, or at least a few, food plants; others with a somewhat wider spectrum of acceptable food plants (see for instance Seppänen 1954). Although relevant data are incomplete, we have good reason to assume that microlepidopteran species contain more food specialists than macrolepidoptera do. Against this biological background, we can easily understand how a change in the environment and in the way the land is used will influence the floral composition, vegetation, and thus the welfare of numerous species of moths. Restructuring the Finnish agriculture has resulted in huge changes from small units to much larger ones. This has especially led to a decrease in various meadow habitats (e.g. Vainio et al. 2001, Kivinen et al. 2008) and is reflected by the dwindling numbers of certain moth species that depend on the presence of such meadows (Rassi et al. 2010).

One very large scale change in the environment has been due to reforms in the forestry industry. Here the splitting of large forest areas into much smaller units has to be mentioned as an ongoing process. As a consequence, the age structure of the forests has become much younger (Várkonyi & Leinonen 2004). Yet the changes mentioned above should speed up species declines and lead to the disappearance of some species, not an increase and range expansion. Therefore the reason for the observed northward expansion of many species must be sought elsewhere and most likely climate change, i.e. global warming, is involved.

4.2 The role of global warming

What kinds of species are invading Finland now? Our results from Kainuu show that many new arrivals prefer meadows and cultural surroundings. Many of them are also living on decorative plants or plants of ruderate areas. This seems to be in disagreement with what had been stated above, e.g., the decrease of meadow habitats, age-structural changes in forest trees, etc. However, we need to remember we were referring to mostly dry habitats. Wetter meadows have in fact been increasing, at least locally (Kivinen et al. 2008). Furthermore, the changes in forestry practices have resulted in increased clear cuts, which in the first steps of succession act like meadows and after some years turn into thick bush, both not only acceptable, but frequently preferred to other habitats, like for instance dense forests, by new arrivals. Mikkola (1997) stated that expansive species are mostly associated with bushes and trees. Although Finland is still largely covered by forests, especially along the eastern and northern parts, it is quite clear that many species cannot unlimitedly migrate northward, where suitable habitats (and to a lesser extent the required food plants) are missing. This holds true in spite of the fact that the changing climate would suit some of these expanding species. Virtanen & Neuvonen (1999) state that the northern limit of the macrolepidopteran distribution in Finland is principally determined by climatic factors, with food plants probably determining distributions in no more than 3 % of the species. This may apply to permanent and long-established species, but in the case of new arrivals the situation could be different. We can only speculate how many of the new arrivals might have been able to settle down in Finland and Kainuu, if the environment had been the same as, say, some 50 or 60 years ago!

Species overwintering as eggs or adults would be expected to benefit from a rise in winter temperature (Virtanen & Neuvonen 1999), because in their analyses from different geographical zones in Finland these authors were able to show, how in southern areas the proportion of adult and egg hibernators was large and, on the other hand, in northern areas larval hibernation was dominating. In our results from the Kainuu area there is some support for this view: in the new microlepidopterous arrivals there were rather many species wintering as eggs. Noteworthy is, however, that the proportion of imago hibernators has not yet significantly increased in the Kainuu area.

4.3 Summary

In summary, drastic changes of the moth fauna are presently taking place in Finland both at state level and the local scale, for instance the Kainuu area. We can only speculate how huge this change may be on a global scale or at least with regard to the northern hemisphere alone. Volney and Fleming (2000), cited in http://www.eoearth.org/article/Climate_change_and_insects_as_a_forest_disturbance_in_the_arctic, have attempted to predict what impact the global change might have on insects of boreal forests. Huang et al. (2010) have tried to do the same for the subtropical island nation of Taiwan. Not surprisingly, emphasis has been on possible effects of destructive moths and their range expansions (Vanhanen et al. 2007; Huang et al. 2010), but climate change and its consequences on lepidopteran diseases have also come under scrutiny, for example at the Centre for Ecology and Hydrology of the United Kingdom (http://www.ceh.ac.uk) and in the United States (Altizer and de Roode 2010).

That moths not only expand their ranges into higher latitudes but also into areas of higher elevation has been shown for tropical regions (Chen et al. 2009) and that a warmer climate, in the case of the winter moth *Operophtera brumata*, can disrupt the synchrony of oak and insect phenology has been examined by Visser and Holleman (2001). Because of the usefulness of Lepidoptera as an indicator of climate change (Forester et al. 2010), studies on distributions and abundances of these insects are being conducted on a worldwide scale. It is clear that dramatic changes are taking place, but that moths can also adapt to recent climate changes show observations by Park et al. (2009) from islands in southern Korea. What exactly the ecological consequences of the shifts affecting moth populations (on a global scale) might be with regard to entire ecosystems and biomes, given the roles caterpillars and adult Lepidoptera play in them, is impossible to predict just yet - or perhaps never.

5. Appendix

List of new moth (Lepidoptera) arrivals to Kainuu area in 1987, 1990-2010. Explanation to columns: A = name of the species; B = lepidopterous group (1= microlepidoptera and 2 = macrolepidoptera); C = arrival year; D = habitat classification (see material and methods for the abbreviations); E = state of settlement into Kainuu area (s = a couple of finds, ss = regurlarly found in some places and sss = widespread nowadays at Kainuu); F = found by targeted searching = d and with pheromone = ph; G = hibernating phase (o = ovum, l = larva, p = pupa and i = imago).

A	B	C	D	E	F	G
Gracillaria syringella	1	1993	c	sss		p
Arghyresthia goedartella	1	1995	df	s		l
Eidophasia messingiella	1	1995	m,c			e
Croesia holmiana	1	1995	c	s		e
Loxoterma siderana	1	1995	c	s		l
Exaeretia allisella	1	1997	r,c	ss		l
Trachysmia advenella	1	1998	df,bu			l
Elachista adscitella	1	1999	m,df	s		l
Oncocera semirubella	1	2000	m			l
Limnaecia phragmitella	1	2000	h			l
Echromius ocelleus	1	2001	Mi			i
Loxostege sticticalis	1	2001	Mi			p
Phycitodes lacteellus	1	2001	Mi			
Isoprichtis striatella	1	2001	m,r			p
Synanthedon flaviventris	1	2002	df,bu		d, ph	l
Lobesia abscisana	1	2002	m,r	s		o
Coleophora tamesis	1	2002	h			l
Dipleurina lacustrata	1	2002	cf			l
Nyctegretis lineana	1	2004	m			l
Dichrorampha simpliciana	1	2004	r,c,m			l
Acrolepiopsis assectella	1	2004	c			i
Sophronia semicostella	1	2004	dm			l
Psoricoptera speciosella	1	2005	df,bu			o
Coleophora artemisicolella	1	2006	r,c,m	s		l
Caryocolum blandelloides	1	2006	c,m			o
Cymolomia hartigiana	1	2006	cf			o
Depressaria daucella	1	2007	m,c,r			i
Choreutis pariana	1	2009	c			o
Endothenia ericetana	1	2010	m,bu			l
Xestia sexstrigata	2	1992	c,m,			l
Amphipyra perflua	2	1993	df			e
Colotois pennaria	2	1994	df			e
Fabriciana adippe	2	1994	dm			l
Timandra griseata	2	1995	dm	s		l
Erannis defoliaria	2	1995	df			e
Blepharita amica	2	1995	bu,bu,c			e
Ipimorpha subtusa	2	1996	df			e
Allophyes oxyacanthae	2	1997	bu,r,c			e
Lomographa temerata	2	1999	df,bu	s		p
Cryptocala chardinyi	2	1999	m,c	sss		l
Agrius convolvuli	2	1999	Mi			p
Argynnis paphia	2	2000	m,dm	ss		l
Pyrrhia umbra	2	2000	c,bu			p
Acronicta alni	2	2001	df			p
Photedes fluxa	2	2001	m			l
Schranckia costaestrigalis	2	2001	m,r			l

Idaea biselata	2	2001	df	s	l
Mesoligia literosa	2	2001	m		l
Polia nebulosa	2	2001	bu,cf		l
Photedes captiuncula	2	2002	Mi		l
Staurophora celsia	2	2003	bu,r,df, c	s	e
Catocala sponsa	2	2003	Mi		e
Xestia triangulum	2	2003	bu,c,cf,m		l
Eilema lutarellum	2	2003	m, dm		l
Eupithecia linariata	2	2003	m,r		p
Lomographa bimaculata	2	2003	df,bu		p
Cerastis leucographa	2	2004	bu,r,c		p
Araschnia levana	2	2004	m,c	sss	p
Apamea ophiogramma	2	2004	bu,m,c		l
Macroglossa stellatarum	2	2005	Mi		p
Agrotis ipsilon	2	2005	Mi		i
Cosmia pyralina	2	2005	Mi		e
Apamea scolopacina	2	2005	m,c,bu		l
Catocala nupta	2	2005	Mi		e
Catocala fulminea	2	2005	Mi		e
Arenostola semicana	2	2005	reed bed		e
Paracolax tristalis	2	2005	df		l
Trisateles emortualis	2	2005	df		p
Gortyna flavago	2	2006	c,r,		e
Mniotype satura	2	2006	bu,df,r		e
Ipimorpha retusa	2	2006	df		e
Protodeltote pygarga	2	2006	bu,r,c	s	p
Herminia tarsipennalis	2	2006	df,bu,c		l
Atolmis rubricollis	2	2007	cf		p
Scopula incanata	2	2007	dm,m,c		l
Xestia xanthographa	2	2007	m		l
Larentia clavaria	2	2010	c,r	s	e

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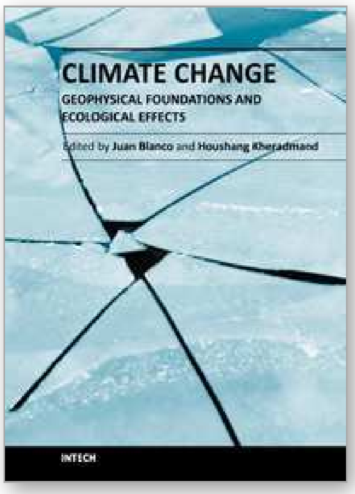

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This book offers an interdisciplinary view of the biophysical issues related to climate change. Climate change is a phenomenon by which the long-term averages of weather events (i.e. temperature, precipitation, wind speed, etc.) that define the climate of a region are not constant but change over time. There have been a series of past periods of climatic change, registered in historical or paleoecological records. In the first section of this book, a series of state-of-the-art research projects explore the biophysical causes for climate change and the techniques currently being used and developed for its detection in several regions of the world. The second section of the book explores the effects that have been reported already on the flora and fauna in different ecosystems around the globe. Among them, the ecosystems and landscapes in arctic and alpine regions are expected to be among the most affected by the change in climate, as they will suffer the more intense changes. The final section of this book explores in detail those issues.

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