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The changing fauna and flora of Finland – discovering the bigger picture through long-term data

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To discern changes in nature during the current era of unprecedented biodiversity change, there is no alternative to systematic long-term data collection efforts. Finland holds a globally unique treasure trove of long-term ecological data series, each springing from its own origins, purposes and approaches. If sensibly used, these data provide a unique baseline for what was before, insight into current directions of change, and a scientifically sound foundation for informed policies. To leverage the mobilisation of these data, we conduct a basic SWOT analysis of the Strengths, Weaknesses, Opportunities, and Threats associated with our national data treasure. As Strengths, we identify the globally unique extent, depth and coverage of data. As Weaknesses, we identify the fragmented nature of data storage, access, and taxonomic coverage. As Opportunities, we show how new syntheses spanning across decades and taxa may reveal both the extent of and mechanisms behind biodiversity change. As Threats, we point to the alarming lack of long-term funding, legislation and coordination of these time series. We conclude that these data provide a unique potential for informing relevant policies – and that this potential can only be secured, tapped and maintained by transformative changes in national monitoring strategies, funding and legislation.

Introduction

The Finns take pride in their nature. Think of the Finnish passport. Where other passports feature statesmen or -women, a statue or a historical site, the Finnish passport show lakes, trees buried in deep snow, a narrow trail dwindling away over a mire, or a boat crossing lake Kilpisjärvi – with iconic Fjeld Saana in the background (Fig. 1A,B). The same iconography applies to our currency. The Finnish markka came with swans and spruces. Now these very themes feature in the euro age: Finnish coins feature water lilies, capercaillies and roan (Fig. 1C). It seems it was always clear to the nation where its identity came from – and from where it derived its wealth.

The modern iconography builds on a long tradition of appreciating national living resources.

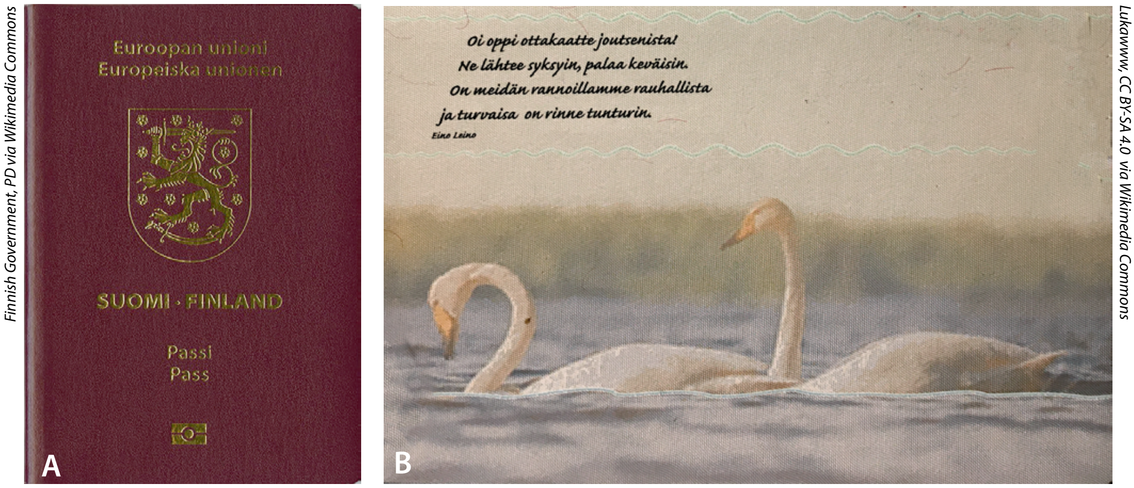

Figure 1. National Finnish iconography featuring nature and wildlife, here illustrated by the Finnish passport (A), its contents (B: individual spread) and national currency (C; including examples from both the era of the Finnish markka and the current euro).

During the current era of unprecedented biodiversity change, our ability to understand and predict what is changing and why is still astonishingly limited. This makes extant data both irreplaceable and infinitely valuable from a both national and international perspective. In our brief essay, we will examine how Finland has systematically surveyed its living nature over time, and how this effort has developed into a national treasure of long-term data. To augment the mobilisation of these data, we will conduct a basic SWOT analysis of the Strengths, Weaknesses, Opportunities, and Threats associated with our national data treasure. But to understand the status quo, we should start by considering how these data came into being.

A brief history of Finnish time series

To discern long-term changes in nature, there is no alternative to observations spread over time. What is more, historical data cannot be generated in hindsight, making any extant records priceless. Finland holds a globally unique treasure trove of long-term data recorded in the past. Today's data are the outcome of a long chain of events.

In the 18th century, when Finland was Sweden, the national economy was in tatters. This misfortune had been brought upon the nation by its wars. For Sweden, the 17th and 18th century were marked by a long series of wars, with the national coffer being emptied by attempts to conquer all Europe. Once Charles XII had eventually been wiped out by a Norwegian bullet, the nation had to be rebuilt. Mapping its living resources was part of this process (Broberg 2019).

The travels of Carl von Linné (Fig. 2) were driven by this utilitarian need. His journeys across Sweden (including Finland) were aimed at mapping its living resources; his task was to explore how nature was and could be used to the benefit of the population and the Crown. Since sensible agricultural practices should be matched with nature's calendar, Linné started mapping when plants and animals awaken in different parts of the reign. For this purpose, Linné and his later successors (including 19th-century professor Hugo Hildebrand Hildebrandsson) recruited the intelligentia of their time, providing eyes and observations across the kingdom. Thus came about the earliest time series: that of phenology – as still continued today (Fig. 3).

Over the centuries, war has continued to be a driver of natural inventories. After the independence of Finland, the new nation needed an inventory of its forest resources. This need spawned the first National Forest Inventory in 1921–1924 (Fig. 4), which was rerun during the harsh economic years of 1936–1938 (Haapanen 2014). The same need grew stronger after the second World War, when the Soviet Union demanded compensation for Finland allegedly causing the war. Since much of the payment was based on forest products, national forest resources were surveyed again in 1951–1953 – now already adding to an established series of snapshots of our forests and their state, later repeated more or less every decade.

Importantly, what was recorded would naturally reflect what was perceived as important. The National Forest Inventory was designed to reflect forest extent and productivity, whereas biodiversity was so far a concept not even minted. Only in later were aspects of diversity added, such as dead wood and surveys of the understory vegetation added to the effort (Anonymous 2016).

Further examples of direct needs to map natural resources are the game triangles initiated by Game and Fisheries Research Institute (currently Luke). To know how much game one can hunt, one needs to know the stock to be hunted. Initially, bag statistics were used to describe changes in stocks. In 1945, a so-called game survey

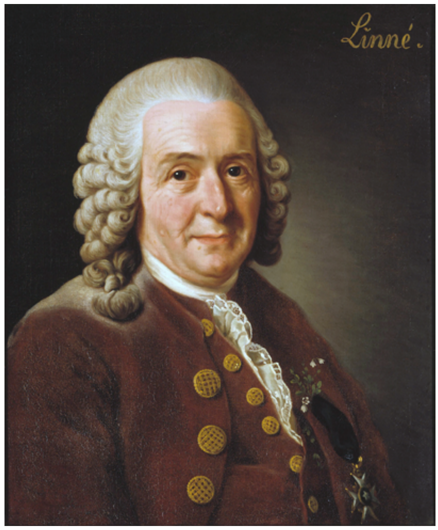

Figure 2. The travels of Carl von Linné were across Sweden and its eastern parts (now Finland).

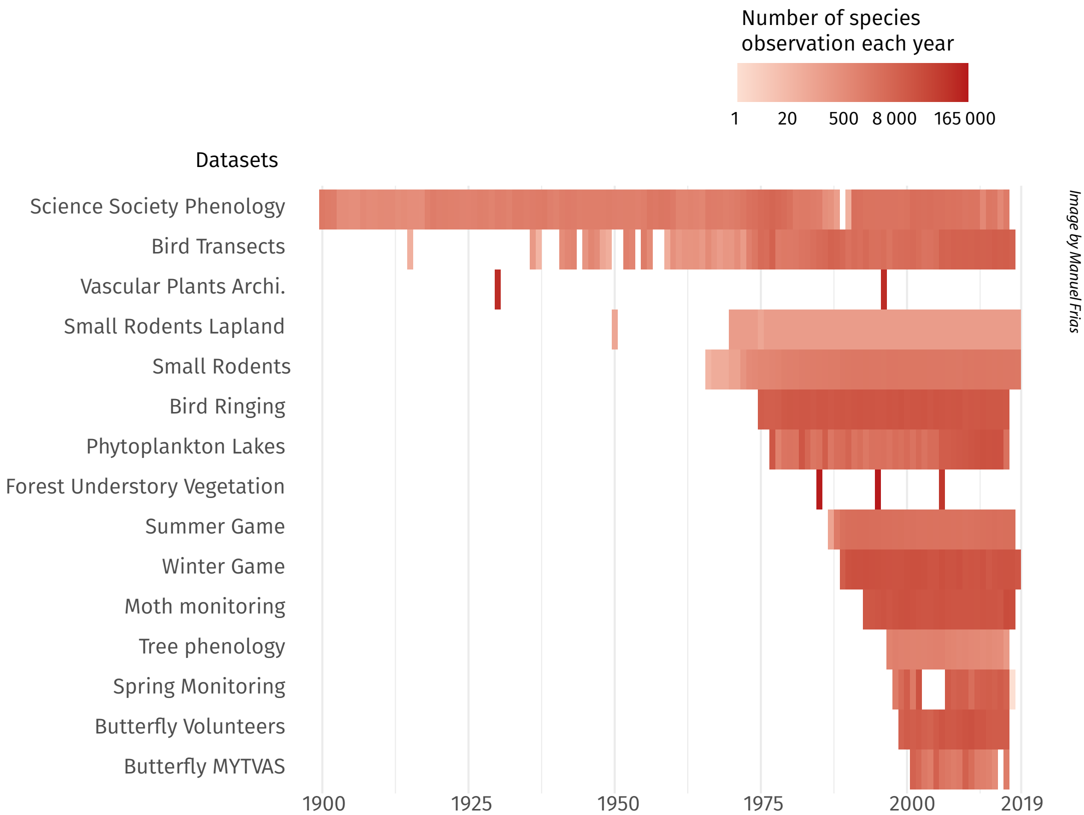

Figure 3. The temporal coverage of Finnish long-term data series. The graph shows both the time span (length of the bar, with decades along the abscissa) and the number of species observations per year (depicted by the colour, with a visual legend at the top right). The density of observations is highest during the last few decades, but some observations go far back in time. Note that the longest time-series was initiated by Carl von Linné (Fig. 2) through the Science Society Phenology, and now spans nearly 270 years. The Forest Understory Vegetation data were collected at 10–11 year intervals until 2006, while other datasets have, in general, been collected on an annual basis. The exception is the data set on Vascular Plants from the South-western Archipelago, which is based on an original survey in the 40s with resurveys in the 2000s (Fig. 4).

was started, in which about 500 observers from all over Finland described the relative abundance of the most common game species in their camping area and the change in the abundance of the stock compared to the previous year. In the monitoring of forest fowl and mammals, transect counts began in the early 1960s. However, the abundance and variability of common game species (and mammals in particular) was poorly understood until the late 1980s. In the 1980s, efforts were made to find a method that would provide information on as many game species as possible through a single census. Late-summer counts were initiated to count broods of game fowl, whereas winter counts were focused on snow tracks – a method long used in Russia. This programme has then been sustained ever since, as implemented by hunters' associations (Lindén et al. 1996; Helle et al. 2016).

Utilitarian inventories springing from the needs of production and usage (above) are but one end of the spectrum. The other extreme are time series springing from the interest and enthusiasm of individual researchers. Ole Eklund (Fig. 5A) was a botanist born in Korpo, an island in the Southwestern archipelago on Finland, in 1899. In 1910, he began compiling a flora over his home municipality. The study area was gradually enlarged and eventually included most of the Archipelago Sea, with thoroughly compiled species lists of the vascular plants from about 1 500 sites (usually individual islets). The most intensive

Figure 4. Field inventory during the first National Forest Inventory in 1921–1924.

work occurred in the 1920s and 1930s, whereas in 1946 Ole Eklund tragically died, at an age of only 47 years. His work was later continued by Mikael von Numers (Fig. 5B), who – likewise, out of own interest – has revisited and resurveyed a massive number of sites in the 21st century, and found massive changes in the occurrence of plants across islands (von Numers & Korvenpää 2007, von Numers 2015). These types of visit-revisit designs provide enormous opportunities for observing large-scale change and their drivers (Opedal et al. 2020).

Somewhere in between the utilitarian and the purely "curiosity-driven" initiatives, we see curiosity-driven initiatives found useful for production, and thus later adopted for utilitarian purposes. A prime example here is the pioneering work of professor Olavi Kalela (Fig. 6A) in exploring population densities of small rodents in Lapland. His enthusiasm was transmitted to his young student Heikki Henttonen (Fig. 6B), who – later a professor himself – has personally generated a more than 50 year-long time series on the population densities of small mammals (voles) in Lapland. The former Forestry Research Institute (now Luke), hired another vole aficionado – Asko Kaikusalo – for recording vole densities across Finland. Given the economic implications of vole damages on silviculture, these originally curiosity-driven time series have since formed the basis for predicting seedling damage, and for understanding the population-dynamic drivers of forest damages by voles (for a classic summary of Nordic time series, see Hanski and Henttonen 2002).

Most recently, we see initiatives being fruitfully adopted in the opposite direction: from utilitarian premises to curiosity-driven science. With Finland's entry into EU, the EU-level ban on national economic subsidies (as biasing competitive constellations) was combined with some EU-

Photo: Memoranda Societatis pro Fauna et Flora Fennica 1947

Photo: Mikael von Numers 2014

Figure 5. The two *primi motori* behind the extensive dataset on vascular plants from the Southwestern Archipelago: Ole Eklund (A; 1899–1946) and Mikael von Numers (B; current chair of Societas pro Fauna et Flora Fennica).

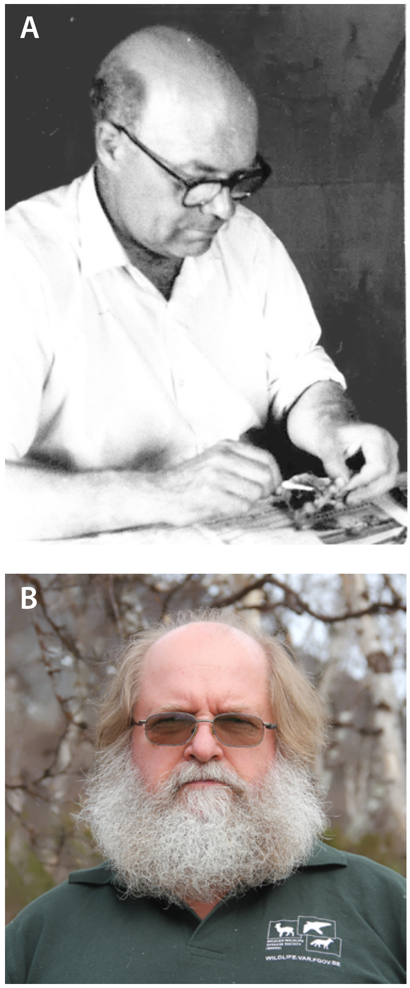

Photo: University of Helsinki

Photo: Heikki Henttonen 2011

Figure 6. The pioneers behind the long-term data on small rodents in Finnish Lapland: professors Olavi Kalela (A) and Heikki Henttonen (B).

support for environmentally-friendly actions. As a result, there was a need to critically evaluate whether environmental subsidies really gave the desired effects. This yielded a series of follow-up studies of the impacts of agri-environment measures (MYTVAS). Here, the potential for using the follow-up studies for some wider scoring of the state of the environment was quickly realised by researchers, yielding both some acrid reports on the true nature of the subsidies (Kleijn & Sutherland 2003; Schulman et al. 2006; Kuussaari et al. 2008; Aakkula et al. 2012) and many insights into basic ecology (e.g. Ekroos et al. 2010; Jonason et al. 2017; Toivonen et al. 2017; Mäkeläinen et al. 2019).

As a result of these semi-independent and internally uncoordinated initiatives, the Finnish state is now the proud owner of millions of records (Fig. 3). Springing from the different origins, purposes and approaches described above, these long-term data now cover our nation as a deep information blanket (Fig. 7).

In terms of their information contents, the long-term data series of Finland form a globally unique treasure trove. These data have been collected systematically using clearly defined methodology, resulting in a unified data format that allows comparative analyses through space and time. As such, these data fulfil the criteria required of any official national statistics. If sensibly used, they provide a unique baseline for what was before, insights into current directions of change, and a scientifically sound foundation for informed policies. Nonetheless, without retracing the roots of each data series, its origins and focus, there is clearly no way we can understand the motley nature of today's data. And without compiling all data in a standardised, accessible format, it is impossible to compare them to each other. Hosted by the University of Helsinki, the Research Centre for Ecological Change (Fig. 8) has been the first research consortium to do so, and to thus gain an overview of the status quo. It is against this background that we will next set out to examine the Strengths, Weaknesses, Opportunities, and Threats associated with our national data treasure.

SWOT – Strengths, Weaknesses, Opportunities, and Threats

Strengths

Long-term data hold a special place in both science and policy. Due to the credibility of such data, both researchers and policy-makers tend to invest particularly high trust in evidence backed by time series (Hughes et al. 2017). From a scientific perspective, we can only discern change by comparing a new state with a previous one. Time series allow us to detect the extent of change, by

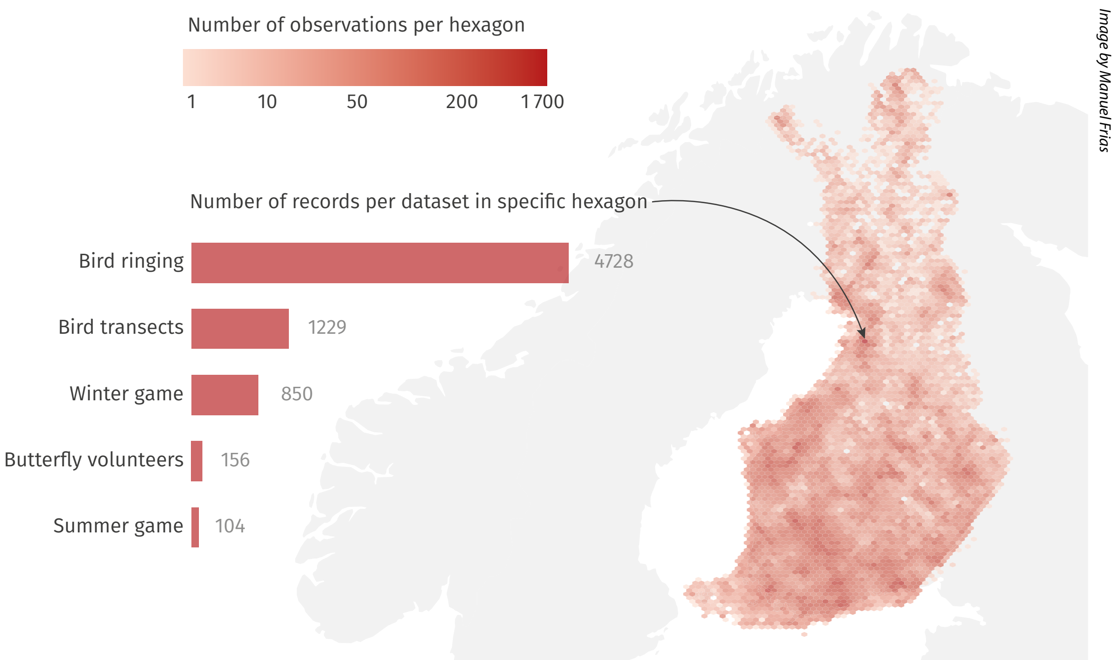

Figure 7. The spatial coverage of Finnish long-term data series. In this map, the area of Finland has been divided into hexagons with a diameter of 10 km. The colour hues shows the total number of records compiled for each hexagon (with a visual legend at the top left). The bar chart inset shows exact figures for records in individual data sets (cf. Fig. 1) for a single, well-studied hexagon.

Figure 8. Members of the Research Centre for Ecological Change, gathered for the World Biodiversity Forum in Davos 2020. From left to right: Laura Antão, Tomas Roslin, Pauliina Hyttinen, Jarno Vanhatalo, Maria Hällfors, Giovanni Strona. Benjamin Weigel, Marjo Saastamoinen, Elina Kaarlejärvi, Anna-Liisa Laine (Director of the Centre) and Manuel Frias.

revealing both what changes and what does not change. If wide and long enough, they will also reveal the spatiotemporal extent, i.e. where and when the change has occurred.

Many Finnish time series are indeed wide and long enough to reveal both past and ongoing change (Fig. 3,7). Consequently, these data are also exceptionally well suited for generating model-based predictions on how nature responds to human driven environmental change – a key requisite when designing policies that account for biodiversity. From a global perspective, national Finnish data series are uniquely rich, deep and long. From a taxonomic perspective, they are diverse – albeit far from comprehensive (see below) – by spanning organisms such as plankton, birds, mammals and moths (Fig. 9). The prime strengths of Finnish long-term data are thus in their sociopolitical credence, in their globally unique extent, in their depth and in their coverage (Table 1).

Weaknesses

What long-term data hold in credibility (see Strengths, above), they lack in causality. Just like any other observational data, they are correlative in nature. By revealing what features change in unison, they may thus point to associations between tentative cause and effect – but they cannot logically prove them without added experiments. Yet, given the practical challenges involved in experimentally manipulating proposed drivers at a relevant scale, correlations will oftentimes be all we can hope for and work with as a basis for policy. The statistical tools for analysing these types of data have improved considerably over time, allowing to quantify also unmeasured variation over space and time, resulting in more robust estimates of the drivers of change (e.g. Cameletti et al. 2012; Norberg et al. 2019).

Weaknesses in causation are certainly shared by any observational data. More specific to the Finnish long-term data is the fragmented nature of data storage, the restrictions on open access, and the gaps in taxonomic coverage (Table 1). At present, both the collection and storage of long-term data are split between Luke (e.g. rodents, other mammals, game species, forest vegetation), SYKE (e.g. plankton, moths, butterflies), the Natural History Museum Luomus (e.g. data on birds from transect counts and ringing, etc) and Åbo Akademi university (vascular plants of the Turku

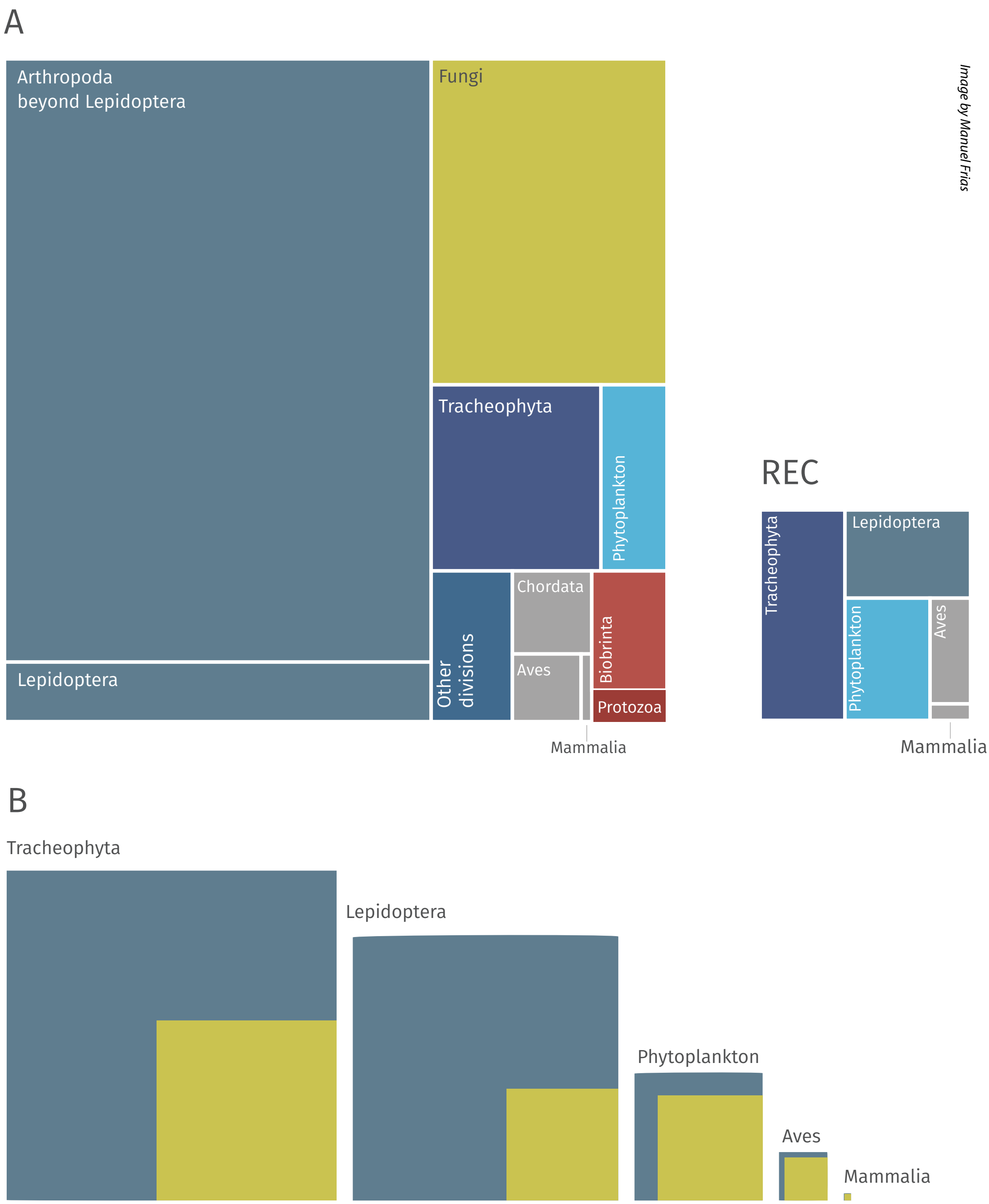

Figure 9. The taxonomic coverage of Finnish long-term data series. Shown in A is the composition of taxa across the full Finnish fauna and flora (left-hand quadrat; figures based on the taxonomic checklist of FinBIF (2022)) versus taxa included in the long-term records compiled by the Research Centre for Ecological Change or REC (right-hand quadrat; data sets summarized in Fig. 3). Shown in B is the group-specific fraction of taxa included in the REC data base, with the dark-blue square showing the total number of taxa listed in Finland and the light-green square showing the taxa included in the data base compiled by REC. For both (A) and (B), the area of each square is proportional to the total number of taxa. Importantly, we note that the taxonomic checklist of FinBIF (2022) is incomplete, as omitting multiple taxa due to gaps in knowledge and current taxonomic expertise. Figures for phytoplankton by courtesy of Benjamin Weigel (REC) and Kristiina Vuorio (SYKE).

Archipelago). There is little or no coordination among these initiatives, and no central data hub through which all data may be accessed (nor anyone responsible for curating them or linking them to the adequate metadata). Making sense of the current data sprawl is no easy task, as individual data sets are currently held by different institutions, collected by different means, and their synthesis has never been planned in any coordinated manner.

At present, the utilisation of the Finnish data treasure is seriously compromised by conservative policies for data sharing. As all long-term data series were initiated before the paradigm shift to open science, access to several long-term data series is still restricted and their curation into easily accessible data with associated metadata has not always been completed. This results in a peculiar jungle of study-specific permits and legal agreements – despite the striking fact that most of these data were generated by public funds, and officially for the use of society.

As a final weakness, the depth and extent of taxon-specific data stand in no proportion to the species richness or perceived ecological importance of the respective taxa (Fig. 9). Some of our least diverse taxa (birds and mammals) account for the lion's share of all records, whereas some of the most diverse and ecologically important taxa (such as fungi; Clemmensen et al. 2013; Tedersoo et al. 2014, 2020) remain outside of all systematic monitoring efforts (save some habitat- and species-specific re-surveys). This status quo was brought into broad daylight by the global interest in insect decline, as breaking in 2017 (e.g. Hallmann et al. 2017, Sánchez-Bayo & Wyckhuys 2019). With a sudden interest in insect abundances and population trends, Finland proved as poorly prepared as the rest of the world to report on the status and trends of the nation's presumably most diverse organism group. To the credit of the nation, Finland did hold long-term records of both moths and butterflies (order Lepidoptera), as for both of these groups, monitoring programmes had been initiated during the last half-century (Fig. 3; Heliölä et al. 2010, Leinonen et al. 2016). In response to this knowledge gap, a national pollinator survey is currently being developed (Heliölä et al. 2021).

Opportunities

Until 2018, no single research team or institution or research team had compiled Finnish long-term records across taxa (see Fig. 3). The opportunities inherent of such a compilation are clearly immense (Table 1). By comparing long-term trends among taxa and regions, one may reveal both the extent of biodiversity change in Finnish nature, and point to its underlying drivers. A compilation of data at hand will also suggest knowledge gaps, and form the basis of any strategic planning of the future monitoring of Finnish nature.

In illustration of the extensive opportunities at hand, Antão et al. (2022) recently combined four decades of climatic data with distributional data for 1,478 species of birds, mammals, butterflies, moths, plants and phytoplankton across Finland. They found that climate change has been rapid during the study period, with stronger increases in temperature and precipitation in northernmost Finland compared to the mid- and southern zones, and a drastic decrease in the duration of snow cover across the country (Fig. 10). These changes have not been reflected in any drastic turnover of species among decades, but instead in prevalent shifts in the relative position of species within their climatic niche (Fig. 11). At higher latitudes, where climatic changes have been stronger, a greater proportion of species have responded to climatic change.

The patterns resolved by Antão et al. (2022) are as drastic as they are transformative. They reveal how climatic imprints are restructuring Finnish biomes, with different species respond in different ways. For a nation which has sired the classification of both species (Linnæus 1753, 1758) and communities (Hult 1881), and the classification of forest types as based on species combinations (Cajander 1949), these findings run deep, by challenging the view that communities come as pre-set types, or can be managed as stable entities.

Importantly, none of these insights had been possible by focusing on a taxon-specific time series on its own – the pattern can only be extracted by comparing taxa and latitudes to each other, and by combining long-term data on climate with long-term data on living nature. The example above highlights the untapped opportunities of Finnish long-term data.

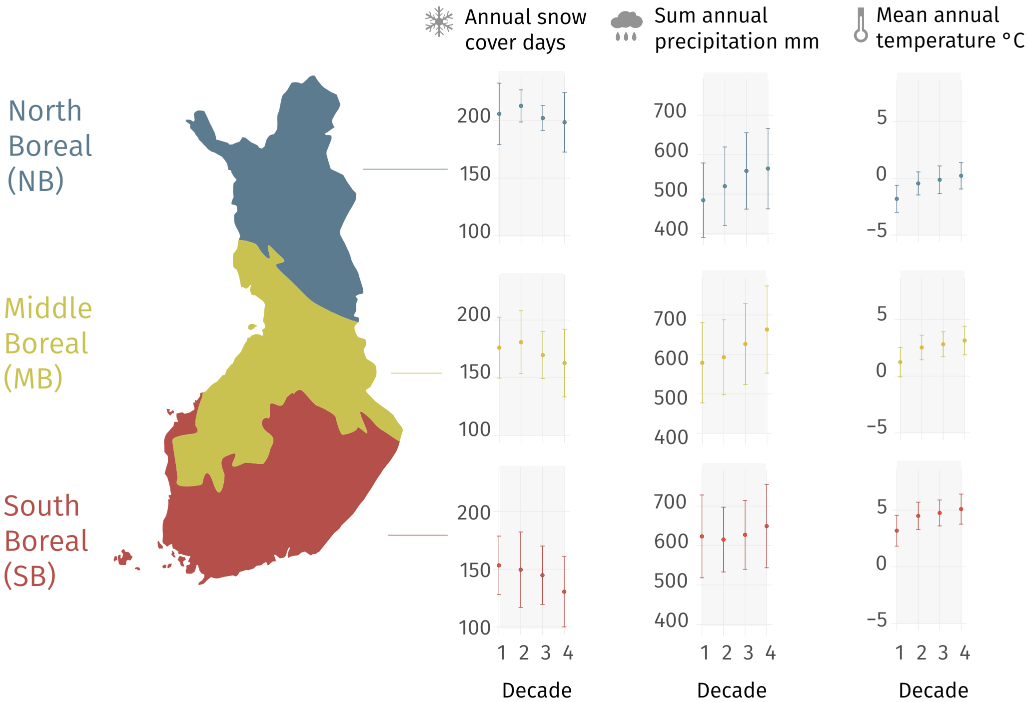

Figure 10. Climate change during the past four decades in different parts of Finland. Shown are means and standard deviations for annual mean temperature, sum precipitation and snow cover days in each of the biogeographical zones depicted on the left and analysed by Antão et al. (2022), with the decades corresponding to 1: 1978–1987, 2: 1988–1997, 3: 1998–2007 and 4: 2008–2017. Image courtesy of Laura Antão, Benjamin Weigel and Manuel Frias, data from Antão et al. (2022).

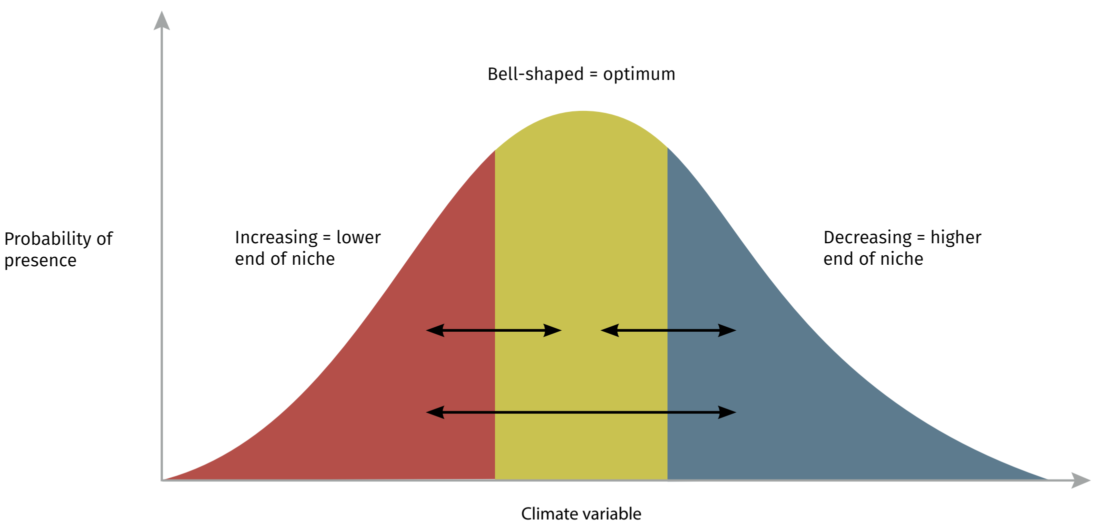

Figure 11. Conceptual illustration of the main type of changes observed among Finnish plants and animals with progressing climate change. The climatic shifts summarised in Fig. 10 have resulted in prevalent shifts in the relative position of species within their climatic niche. With a warming climate, the relative position of species within their niche has shifted substantially over time. Among decades, a large proportion of species shifted position between the lower end of niche space (where an increase in the climatic covariate has a positive impact on species occurrence), the niche optimum (i.e. the bell-shaped area of the curve) or the upper end (where an increase in the climatic covariate has a negative impact on species occurrence).

Threats

As unique (see Strengths) and scientifically significant (see Opportunities) as the Finnish time series are, their very existence is balanced on a knife's edge. A time-series can only shed new light on changes in the environment if it is maintained intact. Nonetheless, some of the longest running time series have been discontinued (Helama et al. 2020), and there are no guarantees for the continuation of the other ones. The forest understorey vegetation survey was halted for over 15 years despite the fact that forests represent the largest ecosystem in Finland. Finally, in 2021 a new nation-wide forest vegetation survey was launched again. This is commendable, but the data gap of 15 years that coincides with a period of extensive change in both climate and forestry practices considerably limits our ability to understand the drives of change in these plant communities. As key threats, we thus point to the alarming lack of long-term funding, legislation and coordination of these time series (Table 1).

At present, there is no legal obligation for authorities to sustain a single time-series. This basic consideration makes all time-series prone to short-sighted policies and budget cuts. Data not collected in a given year can never be collected again. Current monitoring programmes are typically run on a shoestring, and their coordinators are forced to spend much more time on fighting for their survival than on data curation, let alone on strategic planning for the future. What imperils the future of Finnish time series is thus their spread across institutions, their lack of coordination and their exposure to short-sighted policies.

Recommendations

Our survey of the current state of affairs points to globally unique opportunities – but also to a vast potential so far left untapped. Finland has a long tradition of treasuring its natural riches and of inventorying their state. The resulting data provide a globally unique potential for informing relevant policies, but this potential can only be secured, tapped and maintained by transformative changes in national monitoring strategies, funding and legislation. To overcome the weaknesses and to confront the major threats here identified, we point to four needs: legislation, open access, coordination and strategic planning.

In terms of legislation, only a legally binding framework can secure the future of Finnish programmes. These resources are much too valuable to leave to the vagaries of short-sighted policies. Just as the nation has decided to safeguard key statistics on economics and population structure by legislation on national statistics, so should we lay down the relevant legislation around the collection and maintenance of hard numbers on our joint natural capital.

Table 1. Strengths, Weaknesses, Opportunities, and Threats associated with our national treasure of long-term data series.

Strengths	Weaknesses
• Socio-political credence	• Correlative nature
• Globally unique extent	• Fragmented data generation and storage
• Depth (i.e. numbers of records)	• Restrictions on open access
• Spatiotemporal coverage	• Gaps in taxonomic coverage
Opportunities	**Threats**
• Evidence for extent of change in Finnish nature	• Lack of long-term funding
• Syntheses across taxa and regions	• Lack of legal framework
• Pointers to underlying drivers	• Lack of coordination
• Identification of knowledge gaps	
• Basis for strategic planning of future monitoring	

In terms of open access, we should see to it that current data are really accessible to all. No authority, institution or researcher can claim to be collecting and managing data to the benefit of society unless these data are openly shared. The current shadow of a protectionist past presents a major hurdle to the efficient use of national data.

In terms of coordination, we have pointed to a state where no party had ever compiled extant data for a comprehensive overview. The study by Antão et al. (2022) reveals the massive scientific opportunities inherent in any such exercise, whereas allowing the current state to continue represents a major loss to us all – not least to society. Only by joining forces may we tap the potential of investments already made.

Finally, in terms of strategic planning, the current syntheses of data point to major challenges. As stressed by Antão et al. (2022), recent compilations of extant data point to one major take-home message: different species and species groups in Finnish nature react differently to ongoing change. Thus, there is no simple, overall trend to record. Rather, different taxa and different metrics change in different directions, and overall change can only be characterised by this very multitude of trends.

The pattern resolved is an inconvenient truth. Yet, the beginning of all wisdom is the acknowledgement of facts. Any sensible use of resources calls for knowing what those resources are and how they change in time. If the fact is that change is complex, well then we need to arm ourselves for recording its relevant dimensions.

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