www.nature.com/scientificdata

SCIENTIFIC DATA

OPEN

DATA DESCRIPTOR

Chronicles of nature calendar, a long-term and large-scale multitaxon database on phenology

Otso Ovaskainen *et al.*#

We present an extensive, large-scale, long-term and multitaxon database on phenological and climatic variation, involving 506,186 observation dates acquired in 471 localities in Russian Federation, Ukraine, Uzbekistan, Belarus and Kyrgyzstan. The data cover the period 1890–2018, with 96% of the data being from 1960 onwards. The database is rich in plants, birds and climatic events, but also includes insects, amphibians, reptiles and fungi. The database includes multiple events per species, such as the onset days of leaf unfolding and leaf fall for plants, and the days for first spring and last autumn occurrences for birds. The data were acquired using standardized methods by permanent staff of national parks and nature reserves (87% of the data) and members of a phenological observation network (13% of the data). The database is valuable for exploring how species respond in their phenology to climate change. Large-scale analyses of spatial variation in phenological response can help to better predict the consequences of species and community responses to climate change.

Background & Summary

Phenological dynamics have been recognised as one of the most reliable bio-indicators of species responses to ongoing warming conditions[1]. Together with other adaptive mechanisms (e.g. changes in the spatial distribution and physiological adaptations), phenological change is a key mechanism by which plants and animals adapt to a changing world[2,3]. Many studies have documented that in the northern hemisphere, spring events have become earlier whereas autumn events are occurring later than before, mostly due to rising temperatures[4–6]. Despite this broadly shared response, there are systematic differences in phenological responses to climate change among individual species[7–9], different taxonomic groups and trophic levels[10–12]. Further, while some studies have reported that different species are likely to have evolved distinct phenological responses to environmental cues[13,14], others suggest that many species are synchronised because phenotypic plasticity in phenological response to climate may maintain local adaptation[15,16].

Comprehensive understanding of phenological responses to climate change requires community-wide data that are both long-term and spatially extensive[11,17,18]. Such data are still not common and, with few exceptions[11,17,18], the assessments of broad-scale taxonomic and geographic variations in phenological changes have generally involved meta-analyses[5,19], or analyses of large observational databases that either represent mid-latitude systems[4,5,20] or are characterized by low species richness[13]. Therefore, the spatial variation in phenological dynamics of species communities at large scale is still not well known[13,17]. Yet, this information is essential for understanding how species and communities respond to climate change[16]. A further common problem with many previously published data sets is publication bias. Few scientific journals are keen to publish papers reporting no detectable signal in species response to climate change – which can result in strongly biased conclusions in meta-analyses (but see[12,13]). Assembling monitoring data which has been consistently collected over long time and a large spatial extent addresses these problems directly[12].

We present a large-scale and long-term dataset that can be used to examine community-level spatial variation in phenological dynamics and its climatic drivers. The database consists of 506,186 observation dates collected in 471 localities in the Russian Federation, Ukraine, Uzbekistan, Belarus and Kyrgyzstan (Fig. 1) over a 129-year period (from 1890 to 2018). During this period, researchers intensively conducted regular observations to record dates at which a predefined list of phenological and climatic events (Fig. 2) occurred. Although 96% of

#A full list of authors and their affiliations appears at the end of the paper.

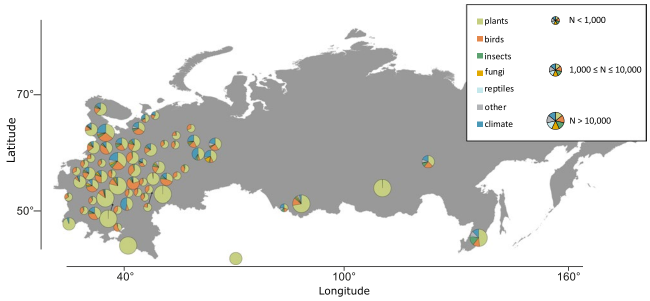

Fig. 1 Spatial and taxonomic distribution of data. The size of each circle shows the total number of phenological observations, and the coloured sectors the proportions of observations belonging to each taxonomical group. The number of distinct localities in the database is 471, but in the figure data from nearby locations have been pooled into 63 locations which are situated at least 100 km apart.

Group	Phenological events	N	L	S	S/L
Plantae	Onset of blooming	76527	317	845	12.2
Plantae	Onset of leaf unfolding	29395	286	393	4.8
Plantae	End of blooming	26243	91	489	14.5
Plantae	Onset of fruiting (ripe)	26009	110	446	10.9
Plantae	Onset of mass blooming	24866	88	476	13.8
Plantae	Onset of flower budding	19667	83	445	10.9
Plantae	Mass fruiting	18026	79	367	10.4
Plantae	Onset of autumn colouring	16262	245	202	3.3
Plantae	Leaf fall end	15501	254	160	3.2
Plantae	Start of vegetation	14159	50	321	13
Plantae	Onset of fruiting (unripe)	13013	40	248	13
Plantae	Onset of leaf fall	10809	102	160	5.6
Plantae	Onset of fruit dispersion	10736	71	270	8.2
Plantae	Start swelling of buds	9330	60	149	8.5
Plantae	Full autumn colouring of leaves	8970	67	153	7.3
Plantae	Onset of withering away	6933	44	202	8.2
Plantae	Onset of budburst	5865	37	156	8.5
Plantae	End of mass blooming	5786	30	159	10.5
Plantae	End of fruit dispersion	4558	22	146	10.7
Plantae	Onset of sap bleeding	4335	182	7	1
Plantae	Mass leaf fall	4167	47	67	5
Plantae	Emergence of seedlings	3943	34	112	6.4
Plantae	Completely withered away	3944	18	105	12.6
Plantae	Leaf unfolding complete	3832	45	131	5.8
Plantae	Mass autumn colouring	3644	54	85	4.6
Plantae	Onset of shoot growth	2551	20	52	5
Plantae	Mass fruit dispersion	2416	17	49	9.7
Plantae	Onset of greening of leaf buds	2276	5	28	13.2
Plantae	Onset opening of flower buds	1931	5	27	13
Plantae	Mass opening of flower buds	1900	5	27	13
Plantae	Onset of pollen releasing	1833	42	28	2.5
Plantae	Autumn colouring of leaves[1]	1359	10	24	5
Plantae	Autumn colouring of leaves[2]	1081	3	25	9
Fungi	1st occurrence	3134	41	32	4.8
Aves	1st occurrence	26258	220	223	6.6
Aves	1st song	12523	217	94	2.8
Aves	Last occurrence	2991	35	65	6.7
Aves	Start of display flights	1151	32	36	3.4
Aves	1st brood	1198	32	11	2.6
Insecta	1st occurrence	10051	210	74	4.2
Insecta	Massive occurrence	1813	66	33	5.1
Reptilia	1st occurrence	1323	76	14	2
Climate		31885	97	216	15.8

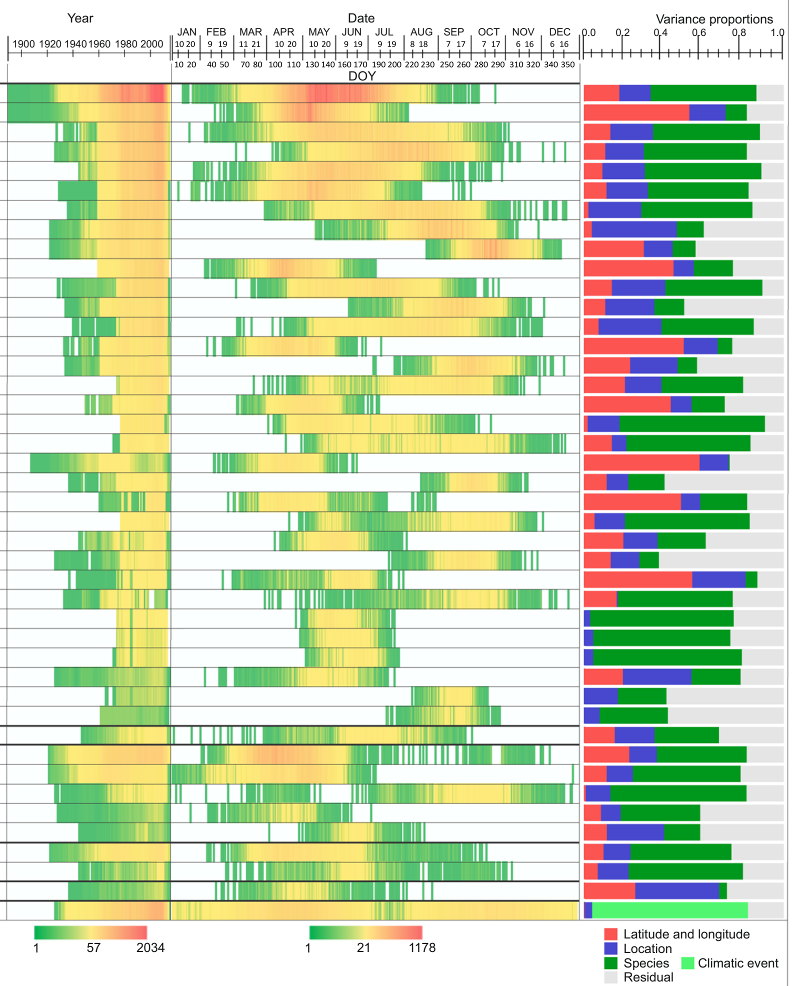

Fig. 2 Illustration of the structure of the data for phenological events with highest coverage. Each row corresponds to a type of phenological event. For each event, shown are the total number of records (N), the number of locations from which the records originate (L), the number of species that the data involve (S), and the mean number of species per location (S/L). The two heat maps show the temporal coverage of data in terms of years included (reflecting data availability), and in terms of the phenological dates (reflecting the timing of the included events). Further shown is a variance partitioning, with the colours corresponding to the fixed effects of latitude, longitude and their interaction (red), the random effect of the site (blue), the random effect of the taxon or climatic parameter (green), and the residual (grey). The event types are ordered within each taxonomic group according to the total amount of data.

the observations were acquired from 1960 onwards, a few time series are very long. Events measured for plants include e.g. the onset days of leaf unfolding, first flowering time, and leaf fall; for birds they include e.g. days for first spring and last autumn occurrences; for insects, amphibians, reptiles and fungi they include e.g. day of first occurrence in the spring. The plant data were acquired in fixed plots, and the bird data along established routes. Climatic events were recorded as calendar dates when those events took place. Of all phenological dates, 87% were collected by research personnel of nature protected areas and national parks, who followed a systematic protocol. Thus, sampling effort remained nearly constant over time. The remaining 13% of the observations came from a well-established volunteer phenological network of volunteers, who followed a similar systematic protocol.

The recording scheme implemented at nature reserves offers unique opportunities for addressing community-level change across replicate local communities[21]. These data have been systematically collected not as independent monitoring efforts, but using a shared and carefully standardized protocol adapted for each local community. Thus, variability in observation effort is of much less concern than in most other distributed cross-taxon phenological monitoring schemes. To enable analyses of higher-level taxonomical groups, we have included taxonomic classifications for the species in the database.

Methods

Data acquisition. The data were collected by two research programs: the Chronicles of Nature (*Letopisi Prirody*) monitoring program, and a volunteer network of phenological observers (*Fenologicheskii Klub*). The Chronicles of Nature monitoring program[22] is based on the network of strictly protected areas (zapovedniks) and national parks. The program gradually evolved during early 1900s[23] and was formally established in 1940 with the aim of streamlining scientific work in protected areas with standardized methodology among the organizations. The program involves the permanent personnel of each participating organization. The results of the monitoring programs are published annually as Chronicle of Nature books. One printed copy of the books was kept in the office of the participating organization and another copy was sent to the Governmental Environmental Conservation Service (or a corresponding entity depending on the specific point in time).

In the Chronicles of Nature monitoring program, bird phenological events are extracted from route-based observations conducted regularly by ornithologists or professional rangers of the protected areas. Plant phenological events are reported either by botanists who visit permanent monitoring plots or transect, or by rangers who conduct regular walk-throughs within the strictly protected area or national park. The insect phenological data are extracted from standardized trapping data collected by entomologists on permanent plots or transects. The amphibian and reptile data are extracted from standardized trapping data collected by herpetologists. The fungal phenological data are collected by mycologists on permanent plots or transects. The weather event data are collected following a list of pre-defined events (e.g. first day of snowfall) by dedicated personnel or sourced from observations made on a local meteorological station. The types of data collected by each organization depends on the expertise of different taxonomic groups in the scientific personnel. For more details on how the data were collected, see[22,24–28].

The network of phenological volunteer observers was established by the Russian Geographic Society in 1848 with questionnaires sent out to selected contacts among scientific community, including teachers and general public[29]. The participants of the volunteer observation network make observations throughout the year to collect data on a pre-defined limited set of phenological events related to plants, animals, and weather. The species included in the pre-defined lists were selected so that they could be identified reliably without specific taxonomical training.

Data digitalization and unification. The compilation of the data in a common database was initiated in the context of the project "Linking environmental change to biodiversity change: long-term and large-scale data on European boreal forest biodiversity" (EBFB), funded for 2011–2015 by the Academy of Finland, and continued with the help of other funding to OO since 2016. We organized a series of project meetings that were essential for data acquisition, digitalization and unification. These meetings were organized in Ekaterinburg (Russia) by the Institute of Plant and Animal Ecology, Ural Branch of RAS (Russian Academy of Sciences) in 2011; in Petrozavodsk (Russia) by the Forest Research Institute, at the Karelian Research Center, RAS in 2013; in Miass (Russia) by the Ilmen Nature Reserve in 2014; in Krasnoyarsk (Russia) by the Stolby Nature Reserve in 2014; in Artybash (Russia) by the Altaisky Nature Reserve in 2015; in Listvyanka, Lake Baikal (Russia) by the Zapovednoe Pribajkalje Nature Reserve in 2016; in Roztochja (Ukraine) by the Ministry of Natural Resources of Ukraine in 2016; in Puschino (Russia) by the Prioksko-Terrasniy Nature Reserve in 2017, in Vyshinino (Russia) by the Kenozero National Park in 2018, and in St Petersburg (Russia) by the Komarov Botanical Institute of the Russian Academy of Sciences in 2019.

The compilation of the data into a common database was conducted by the database coordinators (EM and CL) in Helsinki (Finland). Those participants that already held the data in digital format submitted it in the original format, and those that had the data only in paper format digitized it using Excel-based templates developed in the project meetings. Submitted data were processed by the database coordinators according to the following steps:

1. The data were formatted so that each observation (the phenological date of a particular event in a particular locality and year) formed one row in the data table (e.g. un-pivoting tables that involved several years as the columns). The phenological event names were split into event type (e.g. "first occurrence") and species name.
2. The event type names (provided originally typically in Russian) were translated into English and the species names (usually provided in Russian) were identified to scientific names, using dictionaries that were partly developed and verified in the project meetings. All scientific names were periodically verified by mapping them to the Global Biodiversity Information Facility (GBIF) backbone taxonomy[30].

3. We associated each data record with the following set of information fields: (1) project name, i.e. the source organization, (2) dataset name, (3) locality name, (4) unique taxon identifier, (5) scientific taxon name, and (6) event type.
4. We imported the data records in the main database (maintained as an EarthCape database at https://ecn.ecdb.io). During the import, the taxonomic names, locality names, and dataset names were matched against already existing records.
5. The database was published in Zenodo[31].

Updates and limitations. There are at least 150 National Parks and Nature Reserves that collect Chronicles of Nature Book data (in Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine and Uzbekistan). Out of these, the current database covers data from 62 organizations, with the highest coverage in European Russia (Fig. 2). The collection of new data continues in most parks. Thus, the database is not complete, and we aim to support the database with updates, depending on the interest of new partners to join, as well as resources and funding. The technical validation procedures described below will also be applied to any new information included in the database. The resulting new versions of the database will be released through the Zenodo repository to ensure the long-term availability of the database.

The Chronicles of Nature programme involves several kinds of systematically collected data beyond phenology data: e.g. trapping data on small mammals, count data on birds, and yield data on berries and mushrooms[22]. We aim to publish these data as separate data papers.

Data Records

The database is organized in six datasets: (1) a classification of taxa included, (2) a list of phenological events included, (3) a list of climatic events included, (4) information on the study site, (5) the phenology data, and (6) an information sources table for phenology data[31]. All tables are in csv format (columns separated by commas), and their fields are described in Tables 1–6. The tables can be linked to each other using the unique study site names and the unique identifiers for species and climatic evens.

Technical Validation

We asked the contributors to carefully check the validity of the phenological dates prior to submission. While uploading the submitted data to the database, we did manual validation checks to pinpoint data records that were suspicious (e.g. summer events recorded in winter), and sent the suspicious data records back for the contributors for correction or validation. However, given the extensive size of the database, it is likely that the database contains a number of erroneous records. Thus, we performed a series of checks to identify spurious data points and to examine for the strength of biological signal in the data.

First, we fitted for each (site – climatic/species name – event type) triplet a von Mises distribution, i.e. the circular normal distribution, where the circularity was used to connect the last day of the previous year to the first year of the next year. We identified as potentially spurious those records that were beyond the 0.9999367 central confidence interval of the fitted distribution (i.e. points located at least four standard deviations away from the mean, assuming a Gaussian distribution). This filtering revealed 322 severe outliers that were returned to the data owners for validation. If the data owner could neither verify nor correct the exceptional date, we marked this data record as suspicious.

Second, for each (site – climatic/species name – event type) triplet we fitted (i) a single von Mises distribution and (ii) a mixture of two von Mises distributions, and compared the fits of the models (i) and (ii) using the Bayesian Information Criteria (BIC). We identified the data as potentially spurious if the mixture model fitted better to the data with BIC difference of 5 or greater, and if the distance between the estimated means of the distributions in the mixture was greater than 30 days. For 214 such cases, we performed a manual examination of the data. This revealed e.g. the use of identical event names with different actual meaning (e.g. first arrival of the Willow Tit *Parus montanus*, recorded in spring and autumn seasons, and thus related to spring and autumn migration). Next, we repeated exactly the same filtering procedure, but for (climatic/species name – event type) pairs – to ensure that similarly named event types had consistent meaning across all sites.

Major sources of variation in the data. To quantify the main sources of variation and thus to illustrate the types of ecological signals present in the data, we performed a variance partitioning analysis separately for each group of species and phenological events. As predictors, we used species and the location, the latter of which we further explained by the linear effects of latitude, longitude, and their interaction. These analyses were preformed using the LinearModelFit and Variance functions in Mathematica 11.1; Wolfram Research 2018. As an example, let us consider the event type with highest amount of data, which is the onset of blooming for plants. These data consist of 76,527 phenological dates, originating from 317 sites and representing 845 taxa (Fig. 2). We first computed for each site an average day over the species and years, resulting in 317 site-specific dates. These dates describe when plants on average (over years and plant species) have their onset of blooming on each location. While the collection of species included in the study varies from site to site, we still consider these dates meaningful proxies for the overall phenology of the onset of plant blooming. The amount of variation explained by the site-level averages was 33% of the original variance. Out of the variation explained by the site, 54% was further explained by the linear effects of latitude, longitude, and their interaction. We then partitioned the remaining variation (after the effect of site was accounted for) to components that could be attributed to the species (53% of the original variance) and to the residual (14% of the original variance). This analysis provided rather strong

Field name	Description
taxonidentifier	The unique identifier of the taxon
taxon	The scientific name of the taxon
taxonomiclevel	The highest taxonomical level to which the taxon is described
kingdom	Kingdom
phylum	Phylum
class	Class
order	Order
family	Family
genus	Genus
species	Species
gbifkey	The GBIF key for the taxon
gbifstatus	Whether the GBIF status of the taxon is accepted

Table 1. The fields of the taxonomy table (taxonomy.csv).

Field name	Description
kingdom	The kingdom for which the phenological event is relevant
eventtype	The name of the phenological event
description	The description of the phenological event
bbch	BBCH-scale used to identify the phenological development stages of plants[32]

Table 2. The fields of the phenological events table (phenologicalevents.csv).

Field name	Description
group	The type of the climatic event (e.g. related to temperature, snow or ice)
eventtype	The name of the climatic event
description	The description of the climatic event

Table 3. The fields of the climatic events table (climaticevents.csv).

Field name	Description
studysite	The name of the study site
latitude	Latitude (typically of center of protected area)
longitude	Longitude (typically of center of protected area)

Table 4. The fields of the study sites table (studysites.csv).

Field name	Description
project	The name of the project in which the data were collected
dataset	The name of the dataset to which the data belongs to
studysite	The name of the study site in which the data were collected
taxonidentifier	The unique identifier of the taxon ("Climate" for climatic events)
taxon	The scientific name of taxon (climatic group for climatic events)
eventtype	The type of the event
year	The year
dayofyear	The date of the observation as the number of days since January 1st in the focal year
quality	An indicator variable of any quality issues identified with the data

Table 5. The fields of the phenology table (phenology.csv).

Field name	Description
project	The name of the project
source	The type of information sources (mostly Chronicles of Nature Books of the participating organizations)
reference	The references used to extract the phenology data

Table 6. The fields of the information sources table (informationsources.csv).

support for a strong ecological signal being present in the data, as 86% of the variation among the 76,527 data points could be attributed to the main effects of the location and species, and as ca. half of the variation among the locations could be attributed to a simple geographic trend. We note that the residual variation in this analyses should not be interpreted as erroneous noise, as it contains e.g. variation over time, and thus reflects e.g. the impact of climate change on phenology.

We repeated the above described analysis for all groups of phenological events for which there were at least 1000 data records, as well as climatic events related to temperature, snow, and ice. The results are illustrated in Fig. 2. The amount of explained variance is generally relatively high in all cases, suggesting that much of the variation in the data are explained by location and species.

Code availability
Not applicable.

Received: 4 January 2019; Accepted: 17 January 2020;
Published online: 11 February 2020

References
1. Post, E., Forchhammer, M. C., Stenseth, N. C. & Callaghan, T. V. The timing of life-history events in a changing climate. *Proc. R. Soc. B* **268**, 15–23 (2001).
2. Koh, L. P. *et al*. Species Coextinctions and the Biodiversity Crisis. *Science* **305**, 1632–1634 (2004).
3. Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W. & Courchamp, F. Impacts of climate change on the future of biodiversity. *Ecol. Lett.* **15**, 365–377 (2012).
4. Parmesan, C. & Yohe, G. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* **421**, 37–42 (2003).
5. Root, T., Price, J., Hall, K. & Schneider, S. Fingerprints of global warming on wild animals and plants. *Nature* **421**, 57–60 (2003).
6. Ovchinnikova, T., Fomina, V. A., Dolzhkovaja, N. P., Andreeva, E. B. & Sukhovolskii, V. G. Analysis of changes in the timing of seasonal events in woody plants of the Stolby Reserve in connection with climatic factors. *Con. Bor. Zo.* **28**, 54–59 (2011).
7. Parmesan, C. Influences of species, latitudes and methodologies on estimates of phenological response to global warming. *Glob. Chang. Biol.* **13**, 1860–1872 (2007).
8. Both, C., Van Asch, M., Bijlsma, R. G., Van Den Burg, A. B. & Visser, M. E. Climate change and unequal phenological changes across four trophic levels: Constraints or adaptations? *J. Anim. Ecol.* **78**, 73–83 (2009).
9. Cook, B. I. *et al*. Sensitivity of spring phenology to warming across temporal and spatial climate gradients in two independent databases. *Ecosystems* **15**, 1283–1294 (2012).
10. Voigt, W. *et al*. Trophic levels are differentially sensitive to climate. *Ecology* **84**, 2444–2453 (2003).
11. Thackeray, S. J. *et al*. Trophic level asynchrony in rates of phenological change for marine, freshwater and terrestrial environments. *Glob. Chang. Biol.* **16**, 3304–3313 (2010).
12. Thackeray, S. J. *et al*. Phenological sensitivity to climate across taxa and trophic levels. *Nature* **535**, 241–245 (2016).
13. Menzel, A., Sparks, T. H., Estrella, N. & Roy, D. B. Altered geographic and temporal variability in phenology in response to climate change. *Glob. Ecol. Biogeogr.* **15**, 498–504 (2006).
14. Hong, B. C. & Shurin, J. B. Latitudinal variation in the response of tidepool copepods to mean and daily range in temperature. *Ecology* **96**, 2348–2359 (2015).
15. Phillimore, A. B., Stålhandske, S., Smithers, R. J. & Bernard, R. Dissecting the contributions of plasticity and local adaptation to the phenology of a butterfly and its host plants. *Am. Nat.* **180**, 655–670 (2012).
16. Roy, D. B. *et al*. Similarities in butterfly emergence dates among populations suggest local adaptation to climate. *Glob. Chang. Biol.* **21**, 3313–3322 (2015).
17. Doi, H. & Takahashi, M. Latitudinal patterns in the phenological responses of leaf colouring and leaf fall to climate change in Japan. *Glob. Ecol. Biogeogr.* **17**, 556–561 (2008).
18. Primack, R. B. *et al*. Spatial and interspecific variability in phenological responses to warming temperatures. *Biol. Conserv.* **142**, 2569–2577 (2009).
19. Ge, Q., Wang, H., Rutishauser, T. & Dai, J. Phenological response to climate change in China: A meta-analysis. *Glob. Chang. Biol.* **21**, 265–274 (2015).
20. Walther, G. R. *et al*. Ecological responses to recent climate change. *Nature* **416**, 389–395 (2002).
21. Ovaskainen, O. *et al*. Community-level phenological response to climate change. *Proc. Natl. Acad. Sci. USA* **110**, 13434–9 (2013).
22. Filonov, K. P. & Nukhimovskaya, Y. D. *The Chronicles of Nature in Zapovedniks of the USSR. Methodological Notes*. (In Russian, Nauka Press, Moscow, 1990).
23. Spetich, M. A., Kvashnina, A. E., Nukhimovskya, Y. D., Olin, E. & Rhodes, J. History, administration, goals, value, and long-term data of Russia's strictly protected scientific nature reserves. *Nat. Areas J.* **29**, 71–78 (2009).
24. Dobrovolsky, B. V. *Phenology of Insects*. (In Russian, Vysshaya Shkola Publishing House, 1969).
25. Beideman, I. N. *The Study of Plant Phenology in Field Geobotany*. (In Russian, Russian Academy of Sciences, 1960).
26. Preobrazhenskiy, S. M. & Galahov, N. N. *Phenological Monitoring*. (In Russian, Detskoe Gosudarstvennoe Izdatelstvo, Moscow, 1948).
27. Zharkov, I. V. *Basic Nature Observations*. (In Russian, USSR Ministry of Agriculture publishing House, Moscow, 1954).
28. Beideman, I. N. *Methods for Phenology Observations of Plants and Plant Communities*. (In Russian, Nauka Press, Novosibirsk, 1972).
29. *Rural Chronicle, Compiled from Observations Which May Serve to Determine Climate in Russia in 1851*, Vol 1. (in Russian, SPb, 1854).
30. GBIF Secretariat. *GBIF Backbone Taxonomy*, https://doi.org/10.15468/39omei (2017).
31. Ovaskainen, O. *et al*. Chronicles of Nature Calendar, a long-term and large-scale multitaxon database on phenology. *Zenodo*. https://doi.org/10.5281/zenodo.3607556 (2020).
32. Meier, U. *Growth Stages of Mono- and Dicotyledonous Plants. (Blackwell, 1997)*.

Acknowledgements

The field work was conducted as part of the monitoring program of nature reserves, Chronicles of Nature. The work was funded by Academy of Finland, grants 250243, 284601, 309581 (OO); the European Research Council, ERC Starting Grant 205905 (OO); Nordic Environment Finance Corporation Grant (OO); Jane and Aatos Erkko Foundation Grant (OO and TR); University of Helsinki HiLIFE Fellow Grant 2017–2020 (OO); the Kone Foundation 44-6977 (MD); Spanish Ramon y Cajal grant RYC-2014-16263 (MD); the Federal Budget for the Forest Research Institute of Karelian Research Centre Russian Academy of Sciences 220-2017-0003, 0220-2017-0005 (LV, SS and JK); the Russian Foundation for Basic Research Grant 16-08-00510 (LK), and the Ministry of Education and Science of the Russian Federation 0017-2019-0009 (Keldysh Institute of Applied Mathematics, Russian Academy of Sciences) (NI, MSh). Special thanks to other colleagues who helped with data collection, especially A. Beshkarev, G. Bushmakova, T. Butorina, A. Esipov, N. Gordienko, E. Kireeva, V. Koltsova, I. Kurakina, V. Likhvar, I. Likhvar, D. Mirsaitov, M. Nanynets, L. Ovcharenko, L. Rassohina, E. Romanova, A. Shelekhov, N. Shirshova, D. Sizhko, I. Sorokin, H. Subota, V. Syzhko, G. Talanova, P. Valizer and A. Zakusov.

Author contributions

O. Ovaskainen acquired the funding, led the project, organized the project meetings, performed the analyses and contributed to the first draft of the paper. E. Meyke organized the project meetings, organized the data into the database, and contributed to the first draft of the paper. C. Lo participated in the project meetings and organized the data into the database. G. Tikhonov participated in the project meetings, performed the technical validation of the data and contributed to the first draft of the paper. M. Delgado organized the project meetings and contributed to the first draft of the paper. T. Roslin participated in the project meetings and contributed to the first draft of the paper. E. Gurarie participated in the project meetings. M. Abadonova collected the original data and participated in the project meetings. O. Abduraimov collected the original data. O. Adrianova collected the original data. T. Akimova collected the original data. M. Akkiev collected the original data. A. Ananin collected the original data, contributed to organizing the data and participated in the project meetings. E. Andreeva collected the original data and participated in the project meetings. N. Andriychuk collected the original data. M. Antipin collected the original data and participated in the project meetings. K. Arzamascev collected the original data. S. Babina organized the project meetings and collected the original data. M. Babushkin collected the original data and participated in the project meetings. O. Bakin collected the original data and participated in the project meetings. A. Barabancova collected the original data. I. Basilskaja collected the original data. N. Belova collected the original data. N. Belyaeva collected the original data and participated in the project meetings. T. Bespalova collected the original data, contributed to organizing the data and participated in the project meetings. E. Bisikalova collected the original data and participated in the project meetings. A. Bobretsov collected the original data and participated in the project meetings. V. Bobrov organized the project meetings. V. Bobrovskyi collected the original data and participated in the project meetings. E. Bochkareva collected the original data. G. Bogdanov collected the original data and participated in the project meetings. V. Bolshakov organized the project meetings. S. Bondarchuk collected the original data and participated in the project meetings. E. Bukharova collected the original data and participated in the project meetings. A. Butunina collected the original data. Y. Buyvolov organized the project meetings, contributed to organizing the data and collected the original data. A. Buyvolova contributed to organizing the data and participated in the project meetings. Y. Bykov collected the original data. E. Chakhireva collected the original data. O. Chashchina organized the project meetings and collected the original data. N. Cherenkova collected the original data and participated in the project meetings. S. Chistjakov collected the original data and participated in the project meetings. S. Chuhontseva organized the project meetings and collected the original data. E. Davydov collected the original data and participated in the project meetings. V. Demchenko collected the original data. E. Diadicheva collected the original data. A. Dobrolyubov collected the original data and participated in the project meetings. L. Dostoyevskaya collected the original data. S. Drovnina collected the original data and participated in the project meetings. Z. Drozdova collected the original data and participated in the project meetings. A. Dubanaev collected the original data. Y. Dubrovsky collected the original data. S. Elsukov collected the original data. L. Epova collected the original data and participated in the project meetings. O. Ermakova collected the original data. O. Ermakova collected the original data and participated in the project meetings. A. Esengeldenova collected the original data. O. Evstigneev collected the original data. I. Fedchenko collected the original data and participated in the project meetings. V. Fedotova collected the original data, contributed to organizing the data and participated in the project meetings. T. Filatova collected the original data and participated in the project meetings. S. Gashev collected the original data and participated in the project meetings. A. Gavrilov collected the original data and participated in the project meetings. I. Gaydysh collected the original data. D. Golovcov collected the original data and participated in the project meetings. N. Goncharova collected the original data and participated in the project meetings. E. Gorbunova collected the original data and participated in the project meetings. T. Gordeeva collected the original data. V. Grishchenko collected the original data. L. Gromyko collected the original data. V. Hohryakov collected the original data, contributed to organizing the data and participated in the project meetings. A. Hritankov collected the original data. E. Ignatenko collected the original data and participated in the project meetings. S. Igosheva collected the original data and participated in the project meetings. U. Ivanova collected the original data. N. Ivanova organized training in data digitalization and participated in the project meetings. Y. Kalinkin collected the original data. E. Kaygorodova collected the original data and participated in the project meetings. F. Kazansky collected the original data and participated in the project meetings. D. Kiseleva collected the original data. A. Knorre organized the project meetings and collected the original data. L. Kolpashikov collected the original data and participated in the project meetings. E. Korobov collected the original data. H. Korolyova collected the original data. N. Korotkikh collected the original data and contributed to organizing the data. G. Kosenkov collected the original data. S. Kossenko collected the original data. E. Kotlugalyamova collected the original data. E. Kozlovsky collected the original data and participated in the project meetings. V. Kozsheechkin collected the original data and participated in the project meetings. A. Kozurak collected the original data. I. Kozyr collected the original data and participated in the project meetings. A. Krasnopevtseva collected the original data and participated in the project meetings. S. Kruglikov collected the original data. O. Kuberskaya collected the original data and participated in the project meetings. A. Kudryavtsev collected the original data and participated in the project meetings. E. Kulebyakina collected the original data, contributed to organizing the data and participated in the project meetings. Y. Kulsha collected the original data. M. Kupriyanova collected the original data and participated in the project meetings. M. Kurbanbagamaev collected the original data. A. Kutenkov organized the project meetings and collected the original data. N. Kutenkova organized the project meetings and collected the original data. N. Kuyantseva organized the project meetings and collected the original data. A. Kuznetsov collected the original data. E. Larin collected the original data, contributed to organizing the data and participated in the project meetings. P. Lebedev organized the project meetings, collected the original data and contributed to organizing the data. K. Litvinov collected the original data and participated in the project meetings. N. Luzhkova collected the original data, contributed to organizing the data and participated in the project meetings. A. Mahmudov collected the original data. L. Makovkina collected the original data. V. Mamontov collected the original data and participated in the project meetings. S. Mayorova collected the original data. I. Megalinskaja collected the original data and participated in the project meetings. A. Meydus collected the original data and participated in the project meetings. A. Minin collected the original data, contributed to organizing the data and participated in the project meetings. O. Mitrofanov collected the original data. M. Motruk collected the original data. A. Myslenkov collected the original data. N. Nasonova collected the original data. N. Nemtseva collected the original data. I. Nesterova collected the original data. T. Nezdoliy collected the original data and participated in the project meetings. T. Niroda collected the original data. T. Novikova collected the original data. D. Panicheva collected the original data and participated in the project meetings. A. Pavlov collected the original data and participated in the project meetings. K. Pavlova collected the original data and participated in the project meetings. P. Petrenko collected the original data and participated in the project meetings. S. Podolski collected the original data. N. Polikarpova contributed to organizing the data and participated in the project meetings. T. Polyanskaya collected the original data. I. Pospelov collected the original data. E. Pospelova collected the original data. I. Prokhorov organized the project meetings. I. Prokosheva collected the original data, contributed to organizing the data and participated in the project meetings. L. Puchnina collected the original data and participated in the project meetings. I. Putrashyk collected the original data. J. Raiskaya collected the original data. Y. Rozhkov collected the original data and participated in the project meetings. O. Rozhkova collected the original data and participated in the project meetings. M. Rudenko collected the original data and participated in the project meetings. I. Rybnikova collected the original data. S. Rykova collected the original data. M. Sahnevich organized the project meetings and collected the original data. A. Samoylov collected the original data. V. Sanko collected the original data. I. Sapelnikova collected the original data, contributed to organizing the data and participated in the project meetings. S. Sazonov collected the original data. Z. Selyunina collected the original data and participated in the project meetings. K. Shalaeva collected the original data. M. Shashkov organized training in data digitalization and participated in the project meetings. A. Shcherbakov collected the original data. V. Shevchyk collected the original data. S. Shubin collected the original data. E. Shujskaja contributed to organizing the data and participated in the project meetings. R. Sibgatullin collected the original data. N. Sikkila collected the original data and participated in the project meetings. E. Sitnikova collected the original data and participated in the project meetings. A. Sivkov collected the original data. N. Skok collected the original data. S. Skorokhodova organized the project meetings and collected the original data. E. Smirnova collected the original data. G. Sokolova collected the original data. V. Sopin collected the original data. Y. Spasovski collected the original data and participated in the project meetings. S. Stepanov collected the original data. V. Stratiy collected the original data. V. Strekalovskaya collected the original data. A. Sukhov collected the original data. G. Suleymanova collected the original data and participated in the project meetings. L. Sultangareeva collected the original data and participated in the project meetings. V. Teleganova collected the original data. V. Teplov collected the original data. V. Teplova collected the original data. T. Tertitsa collected the original data and participated in the project meetings. V. Timoshkin collected the original data. D. Tirski collected the original data. A. Tolmachev collected the original data. A. Tomilin contributed to data management and participated in the project meetings. L. Tselishcheva collected the original data and participated in the project meetings. M. Turgunov collected the original data. Y. Tyukh collected the original data. V. Van collected the original data. E. Vargot collected the original data and participated in the project meetings. A. Vasin collected the original data. A. Vasina collected the original data and participated in the project meetings. A. Vekliuk collected the original data. L. Vetchinnikova collected the original data and participated in the project meetings. V. Vinogradov collected the original data. N. Volodchenkov collected the original data. I. Voloshina collected the original data. T. Xoliqov collected the original data and participated in the project meetings. E. Yablonovska-Grishchenko collected the original data. V. Yakovlev collected the original data. M. Yakovleva organized the project meetings and collected the original data. O. Yantser collected the original data and contributed to organizing the data. Y. Yarema collected the original data. A. Zahvatov collected the original data. V. Zakharov collected the original data and participated in the project meetings. N. Zelenetskiy collected the original data. A. Zheltukhin collected the original data and participated in the project meetings. T. Zubina collected the original data. J. Kurhinen initiated the establishment of the co-operative network, acted as the network coordinator and organized the project meetings.

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to O.O.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Otso Ovaskainen[1,2✉], Evgeniy Meyke[3], Coong Lo[1], Gleb Tikhonov[1], Maria del Mar Delgado[4], Tomas Roslin[5], Eliezer Gurarie[6], Marina Abadonova[7], Ozodbek Abduraimov[8], Olga Adrianova[9], Tatiana Akimova[10], Muzhigit Akkiev[11], Aleksandr Ananin[12,13], Elena Andreeva[14], Natalia Andriychuk[15], Maxim Antipin[16], Konstantin Arzamascev[17], Svetlana Babina[18], Miroslav Babushkin[19], Oleg Bakin[20], Anna Barabancova[21], Inna Basilskaja[22], Nina Belova[23], Natalia Belyaeva[24], Tatjana Bespalova[25], Evgeniya Bisikalova[26], Anatoly Bobretsov[27], Vladimir Bobrov[28], Vadim Bobrovskyi[29], Elena Bochkareva[30,31], Gennady Bogdanov[32], Vladimir Bolshakov[33], Svetlana Bondarchuk[34], Evgeniya Bukharova[12], Alena Butunina[25], Yuri Buyvolov[35], Anna Buyvolova[35], Yuri Bykov[36], Elena Chakhireva[20], Olga Chashchina[37], Nadezhda Cherenkova[38], Sergej Chistjakov[39], Svetlana Chuhontseva[10], Evgeniy A. Davydov[30,40], Viktor Demchenko[41], Elena Diadicheva[41], Aleksandr Dobrolyubov[42], Ludmila Dostoyevskaya[43], Svetlana Drovnina[38], Zoya Drozdova[36], Akynaly Dubanaev[44], Yuriy Dubrovsky[45], Sergey Elsukov[34], Lidia Epova[46], Olga S Ermakova[47], Olga Ermakova[23], Aleksandra Esengeldenova[25], Oleg Evstigneev[48], Irina Fedchenko[49], Violetta Fedotova[43], Tatiana Filatova[50], Sergey Gashev[51], Anatoliy Gavrilov[52], Irina Gaydysh[9], Dmitrij Golovcov[53], Nadezhda Goncharova[14], Elena Gorbunova[10], Tatyana Gordeeva[54,97], Vitaly Grishchenko[55], Ludmila Gromyko[34], Vladimir Hohryakov[56], Alexander Hritankov[14], Elena Ignatenko[57], Svetlana Igosheva[58], Uliya Ivanova[59], Natalya Ivanova[60], Yury Kalinkin[10], Evgeniya Kaygorodova[48], Fedor Kazansky[61], Darya Kiseleva[62], Anastasia Knorre[14,63], Leonid Kolpashikov[52], Evgenii Korobov[64], Helen Korolyova[10], Natalia Korotkikh[25], Gennadiy Kosenkov[56], Sergey Kossenko[48], Elvira Kotlugalyamova[65], Evgeny Kozlovsky[66], Vladimir Kozsheechkin[14], Alla Kozurak[15], Irina Kozyr[23], Aleksandra Krasnopevtseva[23], Sergey Kruglikov[48], Olga Kuberskaya[29], Aleksey Kudryavtsev[42], Elena Kulebyakina[67], Yuliia Kulsha[55], Margarita Kupriyanova[59], Murad Kurbanbagamaev[27], Anatoliy Kutenkov[68], Nadezhda Kutenkova[68], Nadezhda Kuyantseva[37,69], Andrey Kuznetsov[19], Evgeniy Larin[25], Pavel Lebedev[43,70], Kirill Litvinov[71], Natalia Luzhkova[12], Azizbek Mahmudov[8], Lidiya Makovkina[72], Viktor Mamontov[67], Svetlana Mayorova[36], Irina Megalinskaja[27], Artur Meydus[73,74], Aleksandr Minin[75,76], Oleg Mitrofanov[10], Mykhailo Motruk[77], Aleksandr Myslenkov[72], Nina Nasonova[78], Natalia Nemtseva[19], Irina Nesterova[34], Tamara Nezdoliy[59], Tatyana Niroda[79], Tatiana Novikova[58], Darya Panicheva[61], Alexey Pavlov[20], Klara Pavlova[57], Polina Petrenko[29], Sergei Podolski[57], Natalja Polikarpova[80], Tatiana Polyanskaya[81], Igor Pospelov[52], Elena Pospelova[52], Ilya Prokhorov[82], Irina Prokosheva[83], Lyudmila Puchnina[49], Ivan Putrashyk[79], Julia Raiskaya[73], Yuri Rozhkov[84], Olga Rozhkova[84], Marina Rudenko[85], Irina Rybnikova[19], Svetlana Rykova[49], Miroslava Sahnevich[10], Alexander Samoylov[38], Valeri Sanko[41], Inna Sapelnikova[22], Sergei Sazonov[86,97], Zoya Selyunina[87], Ksenia Shalaeva[56], Maksim Shashkov[88,60],

Anatoliy Shcherbakov[68], Vasyl Shevchyk[55], Sergej Shubin[89], Elena Shujskaja[64], Rustam Sibgatullin[24], Natalia Sikkila[9], Elena Sitnikova[48], Andrei Sivkov[49,97], Nataliya Skok[59], Svetlana Skorokhodova[68], Elena Smirnova[34], Galina Sokolova[35], Vladimir Sopin[73], Yurii Spasovski[90], Sergei Stepanov[64], Vitaliy Stratiy[91], Violetta Strekalovskaya[52], Alexander Sukhov[68], Guzalya Suleymanova[92], Lilija Sultangareeva[65], Viktorija Teleganova[54], Viktor Teplov[27,97], Valentina Teplova[27], Tatiana Tertitsa[27], Vladislav Timoshkin[14], Dmitry Tirski[84], Andrej Tolmachev[21], Aleksey Tomilin[93], Ludmila Tselishcheva[89], Mirabdulla Turgunov[8], Yurij Tyukh[79], Van Vladimir[29], Elena Vargot[94], Aleksander Vasin[95], Aleksandra Vasina[95], Anatoliy Vekliuk[15], Lidia Vetchinnikova[86], Vladislav Vinogradov[14], Nikolay Volodchenkov[23], Inna Voloshina[72], Tura Xoliqov[96], Eugenia Yablonovska-Grishchenko[55], Vladimir Yakovlev[10,97], Marina Yakovleva[68], Oksana Yantser[59], Yurij Yarema[79], Andrey Zahvatov[94], Valery Zakharov[37], Nicolay Zelenetskiy[19], Anatolii Zheltukhin[64], Tatyana Zubina[10] & Juri Kurhinen[1,86]

[1]University of Helsinki, PO BOX 65, 00014, Helsinki, Finland. [2]Centre for Biodiversity Dynamics, Department of Biology, Norwegian University of Science and Technology, N-7491, Trondheim, Norway. [3]EarthCape OY, Latokartanonkaari 3, 00790, Helsinki, Finland. [4]Oviedo University, Research Unit of Biodiversity (UMIB, UO-CSIC-PA), Campus Mieres, 33600, Mieres, Spain. [5]Swedish University of Agricultural Sciences, Department of Ecology, PO BOX 7044, SE-75007, Uppsala, Sweden. [6]University of Maryland, 3237 Biology-Psychology Building, University of Maryland, College Park, MD, 20742, United States. [7]National Park Orlovskoe Polesie, 303943, Orel region, Hotynetskiy district, Zhuderskiy village, Shkolnaya st. 2, Russian Federation. [8]Institute of Botany, Academy of sciences of the Republic of Uzbekistan, 100053, Tashkent, Bogi shamol str. 232 V, Uzbekistan. [9]Kostomuksha Nature Reserve, 186930, Karelia Republic, Kostomuksha, Priozernaya 2, Russian Federation. [10]Altai State Nature Biosphere Reserve, 649000, Altai Republic, Gorno-Altaysk, Naberezhnyi st., 1, Russian Federation. [11]Kabardino-Balkarski Nature Reserve, 360000, Kabardino-Balkaria, Cherek District, Mechieva 78, Russian Federation. [12]FSE Zapovednoe Podlemorye, 671623, Republic of Buryatia, Ust-Bargizin, Lenina st. 71, Russian Federation. [13]Institute of General and Experimental Biology, Siberian Department, Russian Academy of Sciences, 6, Sakhyanovoy str., Ulan-Ude, 670047, The Republic of Buryatia, Russian Federation [14]State Nature Reserve Stolby, 660006, Krasnoyarsk region, Krasnoyarsk, Kariernaya 26, Russian Federation. [15]Carpathian Biosphere Reserve, 90600, Zakarpatska obl., Rakhiv, Krasne Pleso Str. 77, Ukraine. [16]Nizhne-Svirsky State Nature Reserve, 18700, Leningrad Region, Lodeinoe Pole, Svir River, 1, Russian Federation. [17]State Nature Reserve Prisursky, 428034, Cheboksary, Lesnoj, 9, Russian Federation. [18]Zapovednoe Pribajkalje (Bajkalo-Lensky State Nature Reserve, Pribajkalsky National Park), 664050, Irkutsk, Bajkalskaya St., 291B, Russian Federation. [19]Darwin Nature Biosphere Reserve, 162723, Cherepovets District, Vologda Region, Borok, 44, p/o Ploskovo, Russian Federation. [20]Volzhsko-Kamsky National Nature Biosphere Rezerve, 422537, Tatarstan Republic, Zelenodolsk District, p/o Raifa, Sadovy, str. Vechova, 1, Russian Federation. [21]FGBU National Park Shushenskiy Bor, 662710, Krasnoyarsk Region, Shushenskoe, Lugovaja 9, Russian Federation. [22]Voronezhsky Nature Biosphere Reserve, 394080, Centralnaja usadba, Goszapovednik, Voronezh, Russian Federation. [23]Baikalsky State Nature Biosphere Reserve, 671220, Buryatia Republic, Kabansky District, Tankhoy, 34 Krasnogvardeyskaya Street, Russian Federation. [24]Visimsky Nature Biosphere Reserve, 624140, Kirovgrad, Stepana Razina, 23, Russian Federation. [25]Kondinskie Lakes National Park named after L. F. Stashkevich, 628240, Hanty-Mansijsk district, City Sovietsky, Komsomolski st., 5, Russian Federation. [26]Federal State Organization of Joint Direction of Kedrovaya Pad' State Biosphere Nature Reserve and Leopard's Land National Park, 690068, Primorskiy kray, Vladivostok, pr. 100-letiya Vladivostoka 127, Russian Federation. [27]Pechoro-Ilych State Nature Reserve, 169436, Komi Republic, Trinity-Pechora region, Yaksha, Laninoy Street 8, Russian Federation. [28]A. N. Severtsov Institute of Ecology and Evolution, 119071, Moscow, Leninsky Prospect 33, Russian Federation. [29]FGBU Zapovednoye Priamurye, Komsomolskiy Department, 681000, Khabarovskyi krai, Komsomolsk-on-Amur, Mira avenue, 54, Russian Federation. [30]Tigirek State Nature Reserve, 656043, Barnaul, Nikitina street 111, Russian Federation. [31]Institute of Systematics and Ecology of Animals of Siberian Branch of Russian Academy of Science, 930091, Novosibirsk, Frunze 11, Russian Federation. [32]State Nature Reserve Bolshaya Kokshaga, 424038, Mary El Republic, Yoshkar-Ola, Voinov-Internacionalistov 26, Russian Federation. [33]Institute of Plant and Animal Ecology, Ural Branch, Russian Academy of Sciences, 620100, Ekaterinburg, 8 Marta 202/3, Russian Federation. [34]Sikhote-Alin State Nature Biosphere Reserve named after K. G. Abramov, 692150, Primorsky krai, Terney, Partizanskaya 44, Russian Federation. [35]FSBI Priroksko-Terrasniy State Reserve, 142200, Moscow region, Serpukhov district, Danky, Russian Federation. [36]National park Meshchera, 601501, Vladimir region, Gus-Hrustalnyi, Internacionalnaya 111, Russian Federation. [37]Ilmensky State Nature Reserve, Russian Academy of Sciences, Urals Branch, 456317, Chelyabinskaya oblast, Miass, Russian Federation. [38]FGBU National Park Kenozersky, 163000, Arkhangelsk, Embankment of the Northern Dvina, 78, Russian Federation. [39]FGBU GPZ Kologrivskij les im. M.G. Sinicina, 157440, Kostromskaja oblast', Kologriv, Nekrasova 48, Russian Federation. [40]Altai State University, 656049, Lenin Ave. 61, Barnaul, Russian Federation. [41]Pryazovskyi National Nature Park, 72312, Zaporiz'ka oblast, Melitopol, Interkulturna Street, 21/1, Ukraine. [42]State Nature Reserve Privolzhskaya Lesostep, 440031, Penza, Okruzhnaya 12-a, Russian Federation. [43]Komarov Botanical Institute of the Russian Academy of Sciences (BIN RAS), 197376, Saint Petersburg, Professora Popova 2, Russian Federation. [44]Sary-Chelek State Nature Reserve, 715705, Dzalal-Abad region, Aksu district, Arkyt village, Kyrgyzstan. [45]Institute for Evolutionary Ecology NAS Ukraine, 03143, Kiev, Lebedeva 37, Ukraine. [46]FGBU State Nature Reserve Kuznetsk Alatau, 652888, Kemerovo region, Mezhdurechensk, Shakhterev 33-1, Russian Federation. [47]Kerzhenskiy

State Nature Biosphere Reserve, 603001, Nizhny Novgorod, Rozhdestvenskaya 23, Russian Federation. [48]Bryansk Forest Nature Reserve, 242180, Bryansk region, Suzemka district, Nerussa St., Zapovednaya street, 2, Russian Federation. [49]Pinezhsky State Nature Reserve, 164610, Arhangel region, Pinezkiy district, Pinega, Pervomayskaya street, 123 A, Russian Federation. [50]The Central Chernozem State Biosphere Nature Reserve named after Professor V.V. Alyokhin, 305528, Kurskiy region, Kurskiy district, p/o Zapovednoe, Russian Federation. [51]Tyumen State University, 625043, Tyumen, Pirogova str., 3, Russian Federation. [52]Reserves of Taimyr, 666300, Norilsk, str. Talnakhskaya, entrance 2, Russian Federation. [53]Chatkalski National Park, 100059, Toshkent, Shota Rustaveli St., 144-34, Uzbekistan. [54]National Park Ugra, 248007, Kaluga, Prigorodnoe lesnichestvo, 3a, Russian Federation. [55]Kaniv Nature Reserve, 19000, Kaniv, Shevchenko str. 108, Ukraine. [56]Smolenskoe Poozerje National Park, 216270, Smolensk Region, Demidovskiy district, Przhevalskoe, Gurevitch street 19, Russian Federation. [57]FSBI Zeya State Nature Reserve, 676246, Stroitelnaya str. 71, Zeya, Amurskaya Oblast, Russian Federation. [58]Polistovsky State Nature Reserve, 182840, Pskov region, Bezhanitsy district, Bezhanitsy Sovetskaya street, 9B, Russian Federation. [59]Ural State Pedagogical University, 620017, Yekaterinburg, prosp. Kosmonavtov, 26, Russian Federation. [60]Institute of Mathematical Problems of Biology RAS – the Branch of the Keldysh Institute of Applied Mathematics of Russian Academy of Sciences, 142290, Moscow Region, Pushchino, Prof. Vitkevicha 1, Russian Federation. [61]Kronotsky Federal Nature Biosphere Reserve, 684000, Kamchatka region, Yelizovo, Ryabikova street 48, Russian Federation. [62]Zhiguli Nature Reserve, 445362, Samara region, P. Bakhilova Polyana, Zhigulyovskaya 1, Russian Federation. [63]Institute for Ecology and Geography, Siberian Federal University, 660041, Krasnoyarsk, 79 Svobodny pr., Russian Federation. [64]Central Forest State Nature Biosphere Reserve, 172521, Tver region, Nelidovo district, Zapovedniy village, Russian Federation. [65]National Park Bashkirija, 453870, Bashkortostan Republic, Meleuzovskiy district, Nurgush, Abubakirova 1, Russian Federation. [66]State Nature Reserve Kurilsky, 694500, Sakhalin, Juzhno-Kurilsk, Zarechnaya 5, Russian Federation. [67]Vodlozersky National Park, 185002, Karelia, Petrozavodsk, Parkovaya 44, Russian Federation. [68]State Nature Reserve Kivach, 186220, Kondopoga District, Republic of Karelia, Russian Federation. [69]South-Ural Federal University, 4563304, Chelyabinskaya oblast, Miass, ul. Kalinina 37, Russian Federation. [70]Saint-Petersburg State Forest Technical University, 194021, St. Petersburg, Institutsky per. 5, 1-338-3, Russian Federation. [71]Astrakhan Biosphere Reserve, 414021, Astrakhan, Tsaerv River Bank 119, Russian Federation. [72]FSBI United Administration of the Lazovsky State Reserve and national park Zov Tigra, 692980, Primorskiy Krai, Lazovskiy District, Lazo, Centralnaya, 56, Russian Federation. [73]State Nature Reserve Tungusskiy, 660028, Krasnoyarsk region, Krasnoyarsk, Street 27 19, Russian Federation. [74]Krasnoyarsk State Pedagogical University named after V.P. Astafyev, 660049, Krasnoyarsk, Ada Lebedeva st. 89, Russian Federation. [75]Institute of Geography, Russian Academy of Sciences, 119017, Moscow, Staromonetniy 29, Russian Federation. [76]Koltzov Institute of Developmental Biology, Russian Academy of Sciences, 119334, Moscow, Vavilov Street 26, Russian Federation. [77]Carpathian National Nature Park, 78500, Ivano-Frankivsk region, Yaremche, V. Stusa street 6, Ukraine. [78]State Environmental Institution National Park Braslav lakes, 211970, Vitebsk region, Braslav, Dachnaya 1, Belarus. [79]National Park Synevyr, 90041, Zakarpattia Region, Mizhhirs'kyi district, Synevyr-Ostriki, Ukraine. [80]Pasvik State Nature Reserve, 184421, Murmansk region, Nikel, Gvardeyskiy Ave. 43, Russian Federation. [81]Mari Chodra National Park, 425090, Mari El Republic, Zvenigovsky District, Krasnogorsky Settlement, Tsentralnaya Street, 73, Russian Federation. [82]Information-Analytical Centre for Protected Areas, 123242, Moscow, Kapranova side-street 3, Russian Federation. [83]State Nature Reserve Vishersky, 618590, Perm region, Krasnovishersk, Gagarina street 36B, Russian Federation. [84]State Nature Reserve Olekminsky, 678100, Republic Sakha, Olekminsk, Filatova 6, Russian Federation. [85]Crimea Nature Reserve, 298514, Alushta, Partizanskaya, 42, Republic of Crimea. [86]Forest Research Institute Karelian Research Centre Russian Academy of Sciences, 185910, Karelia, Petrozavodsk, Pushkinskaya 11, Russian Federation. [87]Black Sea Biosphere Reserve, 75600, Khersons'ka oblast, Hola Prystan, Mikhail Lermontov 1, Ukraine. [88]Institute of Physicochemical and Biological Problems in Soil Sciences, Russian Academy of Science, 142290, Moscow Region, Pushchino, Institutskaya 2, Russian Federation. [89]State Nature Reserve Nurgush, 610002, Kirov, Lenina street, 129a, Russian Federation. [90]Caucasian State Biosphere Reserve of the Ministry of Natural Resources, 385000, Adygea Republik, Maykop, Sovetskaya str. 187, Russian Federation. [91]National Nature Park Vyzhnytskiy, 59200, Chernivtsi Region, Vyzhnytsya District, Berehomet, Street Central 27 a, Ukraine. [92]National Park Khvalynsky, 412780, Region Saratov, Khvalynsk Sity, Oktyberskya Street, 2b, Russian Federation. [93]State Research Center Arctic and Antarctic Research Institute, 199397, Saint Petersburg, Bering st. 38, Russian Federation. [94]Mordovia State Nature Reserve, 431230, Mordovia Republic, Temnikov region, village Pushta, Russian Federation. [95]State Nature Reserve Malaya Sosva, 628242, Tjumen region, Sovetskiy, Lenina str., 46, Russian Federation. [96]Surhanskiy State Nature Reserve, 191404, Surhandarja region, Sherabad, Agahi, 1, Uzbekistan. [97]Deceased: Tatyana Gordeeva, Sergei Sazonov, Andrei Sivkov, Viktor Teplov, Vladimir Yakovlev. ✉e-mail: otso.ovaskainen@helsinki.fi