D3.1 Palsa mire

Summary

Palsa mire develops where thick peat is subject to sporadic permafrost in Iceland, northern Fennoscandia and arctic Russia where there is low precipitation and an annual mean temperature below -1°C. The permafrost dynamics produce a typical patterning with palsa mounds 2-4m (sometimes 7m) high elevated in central thicker areas by permafrost lenses, the carpet of *Sphagnum* peat limiting the penetration of thaw, and a perennially frozen core of peat, silt and ice lenses beneath. Pounikko hummock ridges can be found in marginal areas subject to seasonal freezing and there are plateau-wide palsas and pounu string mires in the arctic. Intact palsa mounds show a patterning of weakly minerotrophic vegetation with different assemblages of mosses, herbs and sub-shrubs on their tops and sides. Old palsa mounds can become dry and erosion may lead to melting and collapse. Complete melting leaves behind thermokarst ponds. Palsa mires have experienced substantial decline and deterioration in recent years and, although these changes are not yet dramatic, all estimations indicate high probability of collapse as a result of climatic warming. Climate change mitigation measures are decisive to prevent the collapse of this habitat type.

Synthesis

This habitat type is assessed as Critically Endangered (CR) under Criterion E as its probability of collapse within the next 50 years is estimated to be over 50% as a result of climate warming. This quantitative analysis has been performed by reviewing and analyzing published research articles, together with unpublished contributions from experts, by including probabilistic modeling of future trends and linear extrapolation of recent trends to support model predictions.

However, there are certain comments to the assessment that need to be mentioned. First of all, monitoring of the active layer depth was possibly undertaken on big palsa mounds whose degradation may have occurred as part of their natural cycle. Furthermore, palsa mounds themselves are only components of the palsa mire habitats, while other indicators of habitat quality are poorly known and have not been considered in this assessment. In addition, extrapolation of recent trends to the future is heavily dependent on which precise recent period of climate fluctuation was included in the data. It is also noteworthy that there is no complete information available on area cover and decrease throughout the whole distribution of the habitat type.

Overall Category & Criteria			
EU 28		EU 28+	
Red List Category	Red List Criteria	Red List Category	Red List Criteria
Critically Endangered	E	Critically Endangered	E

Sub-habitat types that may require further examination

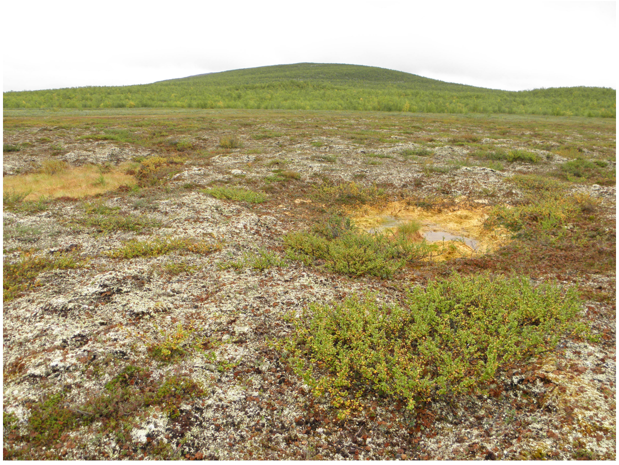
Mires with temporal frost features are poorly known, while they are included as a sub-type of palsa mires in EUNIS (D3.12: *Sphagnum fuscum* pounikko hummocks). They have long-lasting seasonal frost that some years may persist over the summer season but they do not form actual permafrost mounds. These habitats are not fully included in this assessment since all data sources cover actual palsa mires and the main collapse threshold is defined by occurrence of permafrost mounds.

Habitat Type

Code and name

D3.1 Palsa mire

A palsa mound with eroding peat surface and marginal melt of permafrost in northwestern Finnish Lapland at 450 m asl. The whitish colour on the palsa mound surface comes from lichens. Soon after collapse of thawed palsa area, green carpet of *Sphagnum riparium* has filled the created wet microhabitat. (Photo: Teemu Tahvanainen).



A four hectare wide continuous palsa formation at 440 m asl in northwestern Finnish Lapland. Only small depressions with *Sphagnum* and *Eriophorum vaginatum* disrupt the even plateau dominated by lichens and dwarf shrubs like *Betula nana* and *Empetrum nigrum hermaphroditum*. (Photo: Teemu Tahvanainen).

Habitat description

This habitat type is consists of mires in the subarctic region with sporadic permafrost, most characteristically palsa mounds elevated by permafrost lenses. Palsa mires are found in the discontinuous permafrost zone of Iceland, northern Fennoscandia and arctic Russia, in areas with average annual temperature below -1 °C, with climatic optimum between -3 to -5 °C and annual precipitation below 450 mm. Typically, palsa mounds occur in groups in the central, thick-peated areas of palsa mires. Palsa mounds with dome shape are 10-100 m wide and 2-7m high. Other types are longitudinal string-form or extensive plateau- form palsas that reach 1-3 m high. Palsa mound summits are covered by *Sphagnum* peat that insulates heat so that the active layer of thaw is limited to 30-60 cm. The perennial frozen core of palsa mounds consists of frozen peat and silt material with ice lenses and crystals. Pounikko-type hummock ridges (D3.12) formed by seasonal frost action can be found particularly in marginal areas of palsa mires. Palsas can have different successional stages: young palsa formations have *Sphagnum* hummock vegetation, while older palsa mounds become dry and their exposed peat surfaces are subject to erosion that may lead to melting and partial collapse. Completely melted palsas result in the formation of thermokarst ponds.

The palsa mound summits provide dry microhabitats in palsa mires. Typical species growing on the palsa mounds include *Dicranum elongatum*, *Polytrichum strictum*, *Empetrum nigrum* and *Rubus chamaemorus* and many lichens. Sides of palsa mounds often have abundant *Betula nana*, *Ledum palustris* and *Eriophorum vaginatum*. Palsa mires resemble D3.2 Aapa mires in hydrology and vegetation of the wet mire surfaces of areas between the palsa mounds, but regular hummock-string patterning is usually not found. Palsa mires are usually weakly minerotrophic and vegetation types overlap with those of D2.2a Poor fens and D2.3 Quaking mires. In the wet surfaces, *Sphagnum lindbergii*, *S. riparium, Eriophorum angustifolium* and *Carex rotundata* are typical dominant species.

Indicators of good quality:

- Under natural conditions, water table is very close to peat surface in fen areas between palsa mounds and carpets of mosses prevail with abundance of characteristic sedges.
- There are no ditches that drain or disconnect water flow (seepage or overland flow) in the palsa mire complex.
- Only few of the palsa mounds are melting and collapsing, indicating natural dynamics, while most palsa

mounds remain frozen with intact peat cover.

- Seasonal thaw of permafrost, the so called active layer, may reach 50-60 cm, while substantially deeper active layer approaching 1-m depth indicates melting and collapse.

Characteristic species:

Flora

Vascular plants: *Andromeda polifolia, Betula nana, Carex diandra, Carex lapponica, Carex lasiocarpa,*

Carex limosa, Carex livida, Carex magellanica ssp. *irrigua, Carex rariflora, Carex rostrata, Carex rotundata, Carex vesicaria, Chamaedaphne calyculata, Dactylorhiza maculata, Drosera rotundifolia*, *Drosera longifolia, Empetrum nigrum* ssp. *hermaphroditum, Epilobium palustre, Eriophorum angustifolium, Eriophorum scheuchzerii, Eriophorum russeolum, Eriophorum vaginatum, Equisetum fluviatile, Huperzia selago, Juncus stygius, Ledum palustre, Menyanthes trifoliata, Pinguicula villosa, Potentilla palustris, Rubus chamaemorus, Salix lapponum, Tofieldia pusilla, Trichophorum alpinum, Trichophorum cespitosum, Vaccinium oxycoccos, Vaccinium microcarpum, Vaccinium myrtillus, Vaccinium vitis-idaea*

Mosses: *Aulacomnium turgidum, Dicranella cerviculata, Dicranum elongatum, Dicranum fuscescens, Dicranum majus, Dicranum scoparium, Pleurozium schreberi, Pohlia nutans, Sphagnum angustifolium, Sphagnum balticum, Sphagnum fallax, Sphagnum flexuosum,Sphagnum fuscum, Sphagnum jensenii, Sphagnum lindbergii, Sphagnum magellanicum, Sphagnum papillosum, Sphagnum pulchrum, Sphagnum riparium, Sphagnum subsecundum, Straminergon stramineum, Warnstorfia fluitans, Warnstorfia exannulata, Warnstorfia procera*

Lichens: *Alectoria spp., Bryocaulon nigricans, Cladonia* spp., *Coelocaulon aculeatum, Ochrolechia* spp.

Fauna

Birds: *Anthus pratensis, Calcarius lapponicus, Calidris alpina, Carduelis flammea, Gallinago gallinago, Lagopus lagopus, Limicola falcinellus, Limosa lapponica Luscinia svecica, Motacilla flava, Phalaropus lobatus, Philomachus pugnax, Pluvialis apricaria, Tringa glareola*

Classification

This habitat may be equivalent to, or broader than, or narrower than the habitats or ecosystems in the following typologies.

EUNIS:

D3.1 Palsa mires

EuroVegChecklist (alliances)

Mosaic of different alliances

Annex 1:

7320 Palsa mires

Emerald:

D3.1 Palsa mires

MAES-2:

Wetlands

IUCN:

5.4. Bogs, Marshes, Swamps, Fens, Peatlands

Does the habitat type present an outstanding example of typical characteristics of one or more biogeographic regions?

Yes

Regions

Alpine

Boreal

Justification

This habitat type as a very limited distribution in northernmost boreal (subarctic) zone in Fennoscandia, with low precipitation and mean annual temperature below -1 °C.

Geographic occurrence and trends

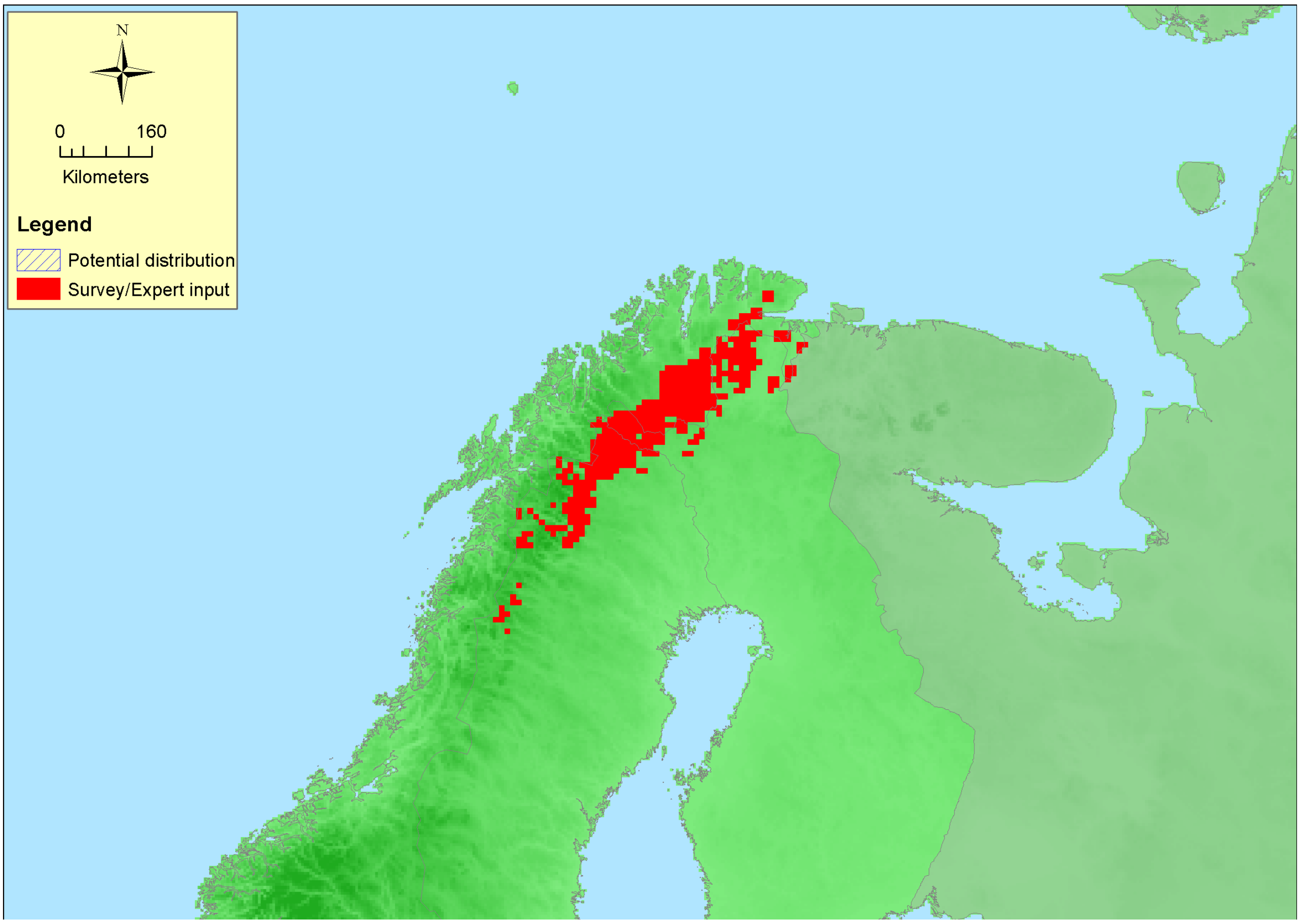
EU 28	Present or Presence Uncertain	Current area of habitat	Recent trend in quantity (last 50 yrs)	Recent trend in quality (last 50 yrs)
Finland	Finland mainland: Present	104 Km^2	Decreasing	Decreasing
Sweden	Present	137 Km^2	Decreasing	Decreasing

EU 28 +	Present or Presence Uncertain	Current area of habitat	Recent trend in quantity (last 50 yrs)	Recent trend in quality (last 50 yrs)
Iceland	Present	Unknown Km^2	Decreasing	Decreasing
Norway	Norway Mainland: Present	150 Km^2	Decreasing	Decreasing

Extent of Occurrence, Area of Occupancy and habitat area

	Extent of Occurrence (EOO)	Area of Occupancy (AOO)	Current estimated Total Area	Comment
EU 28	104750 Km^2	287	241 Km^2	
EU 28+	113150 Km^2	417	391 Km^2	Iceland area missing

Distribution map



The habitat is confined to subarctic climates and hence occurs only in Nordic countries. The Swedish area consists of the total area of 1-hectare grids with occurrence of palsa mounds calculated from a detailed national inventory (Backe 2009). The Finnish habitat area was calculated by considering all habitat patterns with palsa mounds obtained from the spatial data base of Parks and Wildlife Finland (S. Tuominen, personal communication). The area reported from Finland to the Article 17 reporting (417 km^2) is much larger but it comprises whole mire complexes and not just palsa mire habitat, as defined here. The map is complete for the EU28plus, except - possibly - for Iceland. Data sources: Art17, BOHN.

The habitat area reported for Finland in Article 17 reporting is 417 km^2. This, however, includes whole mire complexes with palsa mounds and includes several other habitat types, mainly D3.2 Aapa mires.

How much of the current distribution of the habitat type lies within the EU 28?

Some 5-10% of palsa mires may be located in EU28 in a very rough estimate. Palsa mires occur in subarctic Russia, Alaska and Canada, in addition to the EU28+.

Trends in quantity

The total area of palsa mires is declining because of melting of permafrost and consequent disappearance of palsa mounds and plateaus. There are indications of disappearance of palsas already during the historical time scale following warming after the Little Ice Age when many palsas probably were formed, but this decline has not been quantified. However, some studies give strong indication of declines in palsa area by ca. 50% for the past 50 years. Disappearance of many palsas has been observed in recent years, and a strongly decreasing trend is expected in the future as a result of climate warming.

- Average current trend in quantity (extent)
  EU 28: Decreasing
  EU 28+: Decreasing

- Does the habitat type have a small natural range following regression?
  No
  Justification
  While this habitat has experienced a strong decline, its range is still very wide in the EU 28 and even larger in the EU 28+.
- Does the habitat have a small natural range by reason of its intrinsically restricted area?
  Yes
  Justification
  Palsa mires are limited to northern boreal to subarctic alpine areas with low precipitation and mean annual temperature below -1 C.

Trends in quality

Palsa mires have a decreasing quality trend due to melting of permafrost. Increase of active layer, i.e. the depth from palsa surface to which thaw extends during summer, has increased in many areas, indicating increased probability of collapse. The recent declining trend is well documented in several studies and continuing decline is expected in the future.

- Average current trend in quality
  EU 28: Decreasing
  EU 28+: Decreasing

Pressures and threats

The main pressure to palsa mires is climate change. Both increase of temperatures and precipitation will result into an increased melting of permafrost. Other minor pressures in some localities are off- road driving and trampling, which may increase erosion of palsa hummock surfaces. Additionally, ditching as a result of road construction may alter hydrological conditions. However, many palsa mires are found in wilderness areas with no apparent imminent pressure from land use.

List of pressures and threats

Transportation and service corridors

Paths, tracks, cycling tracks

Human intrusions and disturbances

Off-road motorized driving
Trampling, overuse

Natural System modifications

Human induced changes in hydraulic conditions

Natural biotic and abiotic processes (without catastrophes)

Erosion

Climate change

Temperature changes (e.g. rise of temperature & extremes)
Flooding and rising precipitations

Conservation and management

Only strong climate change mitigation measures can be considered as an effective approach to possibly limit the decline of palsa mires in the future. In some individual cases, restoration and improvement of hydrological regime can be needed. Establishing protection for palsa mires may increase the likelihood of persistence of at least some palsa mires in localities with the most favorable conditions.

List of conservation and management needs

Measures related to wetland, freshwater and coastal habitats

Restoring/Improving the hydrological regime

Measures related to spatial planning

Establish protected areas/sites
Establishing wilderness areas/allowing succession
Legal protection of habitats and species

Conservation status

Annex 1:

7320: ALP U2, BOR U2

When severely damaged, does the habitat retain the capacity to recover its typical character and functionality?

New palsas may form naturally if climate stays favourable or if climate cooling was expected.

Effort required

10 years	20 years	50+ years	200+ years
Unknown	Unknown	Unknown	Unknown

Red List Assessment

Criterion A: Reduction in quantity

Criterion A	A1	A2a	A2b	A3
EU 28	-40 %	Unknown %	Unknown %	Unknown %
EU 28+	-44 %	Unknown %	Unknown %	Unknown %

Based on literature review and unpublished data, an overall decline of 40% in the EU 28 and of 44% in the EU 28+ has been calculated for the past 50 years, and thus the habitat qualifies as Vulnerable under Criterion A. There is no sufficient data available to calculate historic declines, while future declines are assessed in more detail under E criterion.

The decrease by *ca*. 40% of palsa mire habitats in the EU 28 and of 44% in the EU 28+ (inferred from palsa mound area, thermokarst area or habitat area as one hectare grid cells with palsas) is estimated based on several studies: Luoto and Seppälä (2003) found in a Finnish study area that the former distribution of palsas was about three times larger than the present area, based on thermokarst pond occurrence, but part of this change has probably taken part earlier than during the past 50 years. T. Kumpula (unpublished data, pers. comm. 2015) compared aerial images of Nierivuoma palsa complex in Finland with 4.6 km^2 cover and found 48% decrease of 1 Ha grid cells with palsas. In Sweden, Zuidhoff and Kollstrup (2000) found 50% decrease of palsa area in Laivadalen, while Christensen *et al*. (2004) found a 36% decrease of (palsa) hummock area in Stordalen. Finally, Borge (2015) found a 33%, 48% and 71% decrease of palsa area in three separate study areas in Finnmark, northern Norway, indicating slightly higher rate of change than in Finland and Sweden. There was no data available of palsa mire area changes in Iceland. All references of decrease of palsa mire area are limited in areal cover.

Criterion B: Restricted geographic distribution

Criterion B	B1				B2				B3
	EOO	a	b	c	AOO	a	b	c	
EU 28	>50000 Km^2	Yes	Yes	Unknown	>50	Yes	Yes	Unknown	Unknown
EU 28+	>50000 Km^2	Yes	Yes	Unknown	>50	Yes	Yes	Unknown	Unknown

The values of EOO and AOO exceed the thresholds for a threatened Category, and therefore the habitat type is assessed as Least Concern under Criterion B. However, a continuing decline in spatial extent and abiotic and biotic quality has occurred, and climate change is expected to cause a continuing decline in the habitat type within the next 20 years.

Criterion C and D: Reduction in abiotic and/or biotic quality

Criteria C/D	C/D1		C/D2		C/D3	
	Extent affected	Relative severity	Extent affected	Relative severity	Extent affected	Relative severity
EU 28	90 %	Slight %	Unknown %	Unknown %	Unknown %	Unknown %
EU 28+	90 %	Slight %	Unknown %	Unknown %	Unknown %	Unknown %

Criterion C	C1		C2		C3	
	Extent affected	Relative severity	Extent affected	Relative severity	Extent affected	Relative severity
EU 28	90 %	Slight %	Unknown %	Unknown %	Unknown %	Unknown %
EU 28+	90 %	Slight %	Unknown %	Unknown %	Unknown %	Unknown %

Criterion D	D1		D2		D3	
	Extent affected	Relative severity	Extent affected	Relative severity	Extent affected	Relative severity
EU 28	Unknown %	Unknown%	Unknown %	Unknown%	Unknown %	Unknown%
EU 28+	Unknown %	Unknown%	Unknown %	Unknown%	Unknown %	Unknown%

An increase of the active layer depth (i.e. the depth to which permafrost melts during summer) has been reported during recent decades in many areas (Johansson *et al*. 2006, Åkerman and Johansson 2008, Saemundsson *et al.* 2012, T. Kumpula unpublished data), and ground temperatures have also been rising (Sannel *et al*. 2015). These changes are interpreted as "slight" relative severity (more than 30%) of quality, since habitat structure does not necessarily change much as long as the palsa mounds do persist. The extent is considered to be very wide, as the pressure is caused by global climate change and will likely affect most of its extent (90% or more). Thus, this habitat type qualifies as Vulnerable under Criterion C1, as the melting of permafrost is considered an abiotic factor. Biological communities respond to melting and collapse of palsa mounds, and thus the habitat is assessed as Vulnerable also under Criterion C/D1, while there is no information available to separately apply D criteria. There is also no direct information available of future and historical reductions in quality.

Criterion E: Quantitative analysis to evaluate risk of habitat collapse

Criterion E	Probability of collapse
EU 28	>50% within 50 years
EU 28+	>50% within 50 years

Palsa mires are assessed as Critically Endangered (CR) under Criterion E since the probability of collapse within the next 50 years is estimated to be over 50%. The quantitative analyses performed in this assessment are shortly listed below, divided into modeling studies and extrapolations of recent trends.

The following studies incorporating climate modelling and spatial distribution of palsa mires indicate high probability of collapse within next 50 years:

- Fronzek *et al*. (2010): More than 50% of simulations with different climate models indicated 100% collapse in 2041-2070. Median estimates of simulations with three different climate models indicated that less than 10% of area suitable for palsa mires is remaining in 2060s.
- Fronzek *et al.* (2006): Different climate models and two emission scenarios (A2, B2) predicted less than 5% of area suitable for palsa mires remaining in 2070-2099.
- Bosiö *et al*. (2012): Modelling of the climate-vegetational relationship indicated 97% reduction in dry hummock areas of palsas by 2041-2060.

Extrapolation (linear) of recent trends in active layer depth, palsa height, ground temperature and palsa occurence indicate a collapse with high probability within next 50 years:

- Increasing active layer depth precedes the complete melting and disappearance of palsa permafrost and negative correlation is expected between active layer depth and palsa height. Mean active layer depth (cm) predicts palsa height (cm) in a linear model [Height (cm) = -4.39 * Active layer (cm) + 491] with R2 = 0.500 (data from Karlgård 2008, Bosiö nd). Applying this rough model indicates 112 cm threshold for zero height of palsa mound, which could be interpreted as a collapse threshold. Datasets of active layer monitoring (Åkerman and Johansson 2008, Johansson *et al*. 2006, Saemundsson *et al*. 2012) all show increased depth within recent decades (with the oldest data starting from mid-1970s). Linear extrapolation of trends (in all 11 data series) to the future indicate the probability of collapse of ca. 80%. In this calculation, average and standard deviation of predicted depth in 2065 are used to estimate cumulative probability of normal distribution for values higher than the 112 cm threshold.
- Decreasing area of palsa mounds has been observed in Iceland by Saemundsson *et al*. (2012) from 2004 to 2010 in measurements of eight palsa mounds. The data indicates complete disappearance with 74% probability by 2065 of permafrost of these palsa mounds, when linear trend is extrapolated to the future. In this calculation, average and standard deviation of predicted surface area in 2065 are used to estimate cumulative probability of normal distribution for values smaller than zero area.
- Decrease of total area of 1 Ha grid cells with palsa mounds from 250 Ha in 1960 to 131 Ha in 2010 (48%) was observed by Timo Kumpula (unpublished data, 2015) in the Nierivuoma palsa mire (one of the biggest palsa mires in Finland) from detailed interpretation of aerial images. Linear extrapolation of this trend to the future indicates complete disappearance by 2065.
- Zuidhodd and Kolstrup (2000) reported maximum height of six palsa mounds in 1960-1967 and 1997. The linear model indicates a decrease of height by 4 cm per year. Applying prediction standard error, a probability of 97% of collapse by 2065 is indicated. In this calculation, predicted height in 2065 and standard error of prediction are used to estimate cumulative probability of normal distribution for (predicted) values smaller than zero height in 2065.
- Sannel *et al.* (2015) published measurements of annual mean ground temperature in palsa permafrost at 1 and 2 m depths during 2006-2013. These data showed a fluctuating pattern connected to climatic circulation with slight rising trends of 0.02-0.03 degrees per year. Extrapolation of these trends indicate 94 to >99% probability of warming above zero Celsius by 2065. In this calculation, predicted temperature in 2065 and standard error of prediction are used to estimate cumulative probability of normal distribution for (predicted) values higher than zero Celsius in 2065.
- Borge (2015) used aerial images from late 1950s to 2010s to reveal changes in palsa mire area in Finnmark, northern Norway. He found 33%, 48% and 71% decrease of palsa area, in three separate study areas. Among 19 separate mires or study areas, ten are indicated to completely lose palsas if the observed decrease of area continued, indicating a 53% probability of collapse.

The extrapolations of recent decade trends to the future are not realistic since the patterns of fluctuation can be complex and only a simple linear model is applied. More complex modeling would need climatic model input and some mechanisms can involve significant nonlinearities. However, for reasons of parsimony and simplicity of interpretation, as well as paucity of data in many cases, these sources are used in a simple manner. The estimated probabilities/quantities assume that the recent and present trends remain the same over the next 50 years. Furthermore, these extrapolations are presented to support and further test the indications from the actual modeling studies.

Overall assessment "Balance sheet" for EU 28 and EU 28+

	A1	A2a	A2b	A3	B1	B2	B3	C/D1	C/D2	C/D3	C1	C2	C3	D1	D2	D3	E
EU28	VU	DD	DD	DD	LC	LC	DD	VU	DD	DD	VU	DD	DD	DD	DD	DD	CR
EU28+	VU	DD	DD	DD	LC	LC	DD	VU	DD	DD	VU	DD	DD	DD	DD	DD	CR

Overall Category & Criteria			
EU 28		EU 28+	
Red List Category	Red List Criteria	Red List Category	Red List Criteria
Critically Endangered	E	Critically Endangered	E

Confidence in the assessment
High (mainly based on quantitative data sources and/or scientific literature)

Assessors
T. Tahvanainen

Contributors
habitat definition: T, Tahvanainen

Territorial data: M. Hajek, T. Kontula, S. Tuominen, T. Kumpula

Working Group Mires & bogs: C. Bita-Nicolae, M. Hájek, F. Jansen, T. Tahvanainen

Reviewers
M. García Criado

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References

Arnalds, O. 2015. The Soils of Iceland. Springer, New York London. 137 p.

Backe, S. 2009. Kartering av Sveriges palsmyrar. Länsstyrelsens rapportserie nr 4/2014.

Borge A.F. 2015. Development and distribution of palsas in Finnmark, Norterh Norway, for the period 1950s to 2010s. Master thesis in Geosciences. Faculty of Mathematics and Natural Sciences, University of Oslo.

Bosiö, J. Degrading palsa mires in northern Europe. Presentation slides, http://www.lucci.lu.se/pdf/backaskog09/Bosio_Julia_P.pdf

Bosiö J., Johansson M., Callaghan T.V., Johansen B. & Christensen T.R. 2012. Future vegetation changes in thawing subarctic mires and implications for greenhouse gas exchange—a regional assessment. Climatic Change, DOI 10.1007/s10584-012-0445-1.

Christensen T.R., Johansson T., Åkerman H.J., Mastepanov M., Malmer N., Friborg T. & Crill P. 2004. Thawing sub-arctic permafrost: Effects on vegetation and methane emissions. Geophysical Research Letters, 31, L04501, doi:10.1029/2003GL018680.

European Environment Agency. Habitats Directive Article 17 Reporting. 7320: Palsa mires.

Fronzek, S. 2013. Climate change and future distribution of palsa mires: ensemble modelling, probabilities and uncertainties. Monographs of the Boreal Environment Research No. 44.

Fronzek S., Carter T.R., Räisänen J., Ruokolainen L. & Luoto M. 2010. Applying probabilistic projections of climate change with impact models: a case study for sub-arctic palsa mires in Fennoscandia. Climatic Change 99: 515-534. DOI 10.1007/s10584-009-9679-y.

Fronzek S., Luoto M. & Carter T.R. 2006. Potential effect of climate change on the distribution of palsa mires in subarctic Fennoscandia. Climate Research, 32: 1-12.

Hofgaard A. Overvåking av palsmyr. NINA Rapport 42, 154, 257, 364, 476, 586 (several reports).

Johansson T., Malmer N., Crill P.A., Friborg T., Åkerman J.H., Mastepanov M. & Christensen T.R. 2006. Decadal vegetation changes in a northern peatland, greenhouse gas fluxes and net radiative forcing. Global Change Biology, 12: 2352-2369.

Karlgård J. 2008. Degrading palsa mires in northern Europe: Changing vegetation in an altering climate and its potential impact on greenhouse gas fluxes. Geobiosphere Science Center, Lund University, Seminar Series nr 154.

Kumpula T. 2015. (Personal communication on analysis of palsa changes in Finnish Lapland based on aerial images) University of Eastern Finland.

Luoto M., Fronzek S. & Zuidhoff F.S. 2004. Spatial modelling of palsa mires in relation to climate in northern Europe. Earth Surface Processes and Landforms, 29: 1373-1387.

Luoto M. & Seppälä M. 2003. Thermokarst ponds as indicators of the former distribution of palsas in Finnish Lapland. Permafrost and Periglacial Processes, 14: 19-27.

Løbersli E. 2010. Palsa monitoring in Norway. Seminar Sigtuna 27-28.10.2010. http://www.myrar.se/docs/sem2010/Palsa_monitoring_in_Norway-sigtuna_27-28oktober_2010-else_%20lobersli.pdf

Saemundsson T., Arnalds O., Kneisel C., Jonsson H.P. & Decaulne A. 2012. The Orravatnsrustir palsa site in Central Iceland—Palsas in an Aeolian sedimentation environment. Geomorphology 167-168: 13-20.

Sannel, A. B. K., Hugelius, G., Jansson, P. & Kuhry, P. 2015. Permafrost Warming in a Subarctic Peatland – Which Meteorological Controls are Most Important? Permafrost and Periglacial Processes, doi: 10.1002/ppp.1862.

Swindles G.T., Morris P.J., Mullan D., Watson E.J., Turner E., Roland T.P., Amesbury M.J., Kokfelt U., Schoning K., Pratte S., Gallego-Sala A., Charman D.J., Sanderson N., Garneau M., Carrivick J.L, Woulds C., Holden J., Parry L. & Galloway J.M. 2015. The long-term fate of permafrost peatlnds under rapid climate warming. Scientific Reports, 5: 17951, DOI: 10.1038/srep17951.

Zuidhodd, F.S. & Kolstrup, E. 2000. Changes in palsa distribution in relation to climate change in Laivadalen, northern Sweden, especially 1960-1997. Permafrost and Periglacial Processes, 11: 55-69.

Åkerman, H.J. & Johansson, M. 2008. Thawing permafrost and thicker active layers in sub-arctic Sweden.

Permafrost and Periglacial Processes, 19: 279-292.