D.T1.1.3 Report on 'New assessment methods for protection forests in the AS'

GREEN RISK 4 ALPS

WP 1

Responsibility for Deliverable

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1 Introduction

The Interreg project GreenRisk4ALPs (GR4A) aims to develop ecosystem-based risk management strategies for alpine natural hazards, which provide decision support to manage risk in the Alpine Space (AS) under changing climate and socio-economic conditions. To develop, test and implement such strategies, detailed spatial and non-spatial information on mountain forests as Ecosystem-based solution for Disaster Risk Reduction (Eco-DRR) are required.

The initial aim of this report was 1) to provide a documentation of available forest information, i.e. of existing data, and methodologies and techniques used to collect these data, and 2) to determine the forest structure parameters that are needed to model the influence of climate change (CC) scenarios on forest's protective functions and effects.

In this report, we, therefore, give an overview of the principle application and further processing of forest data, which were compiled and collected for the GR4A project and list the main spatial and non-spatial forest data sets that were used for:

1) modeling forest's protective functions and effects against snow avalanches, rockfall and shallow landslide with the regional-scale hazard runout model Flow-py (see D.T1.2.3[1], D.T1.3.3, and D.T3.2.1 for details), and
2) predicting impacts of CC scenarios on the growth and development of protection forests with the forest growth simulator CALDIS (see D.T1.1.1).

The collected data is the basis for several activities that are part of the GR4A work packages (WPs) 1 and 3, in which methods and tools to support ecosystem-based risk management strategies were developed and tested in the six GR4A Pilot Action Regions (PARs):

- PAR1: Val Ferret, Italy
- PAR2: Kranjska Gora, Slovenia
- PAR3: Oberammergau/Ettal, Germany
- PAR4: Parc des Baronnies, France
- PAR5: Southern Wipptal, Italy
- PAR6: Vals/Gries am Brenner, Austria

[1] Citations with the name „D.TX.Y.Z" refer to GR4A reports, which can be found at and downloaded from the GR4A homepage: https://www.alpine-space.eu/projects/greenrisk4alps/en/outputs/downloads

2 Forest data for modeling forest's protective functions and effects

2.1 Data overview, and modeling and data classification principles

The Flow-py model, which was developed at the Austrian Research Centre for Forests (BFW) as a flexible regional-scale gravitational hazard runout model, was employed in GR4A 1) to identify forest areas with a direct object protective function, and 2) to quantify forests' protective effects for the hazard processes snow avalanches, rockfall and shallow landslides (see D.T1.2.3, D.T.1.3.3 and D.T3.2.1). The Flow-py model and two custom-made plugins (the back-calculation plugin and the forest plugin) require therefore spatially-explicit forest input data in 10-m raster format. Here we provide an overview of the forest data that were submitted by the institutions working in each PAR (Table 2), which we classified into three different levels of forest data based on their information level, resolution and content (Table 1), and describe how these data were processed for each PAR to create the 10-m raster forest data sets needed for the Flow-py simulations. In general:

1) To define forest areas with a direct object protective function, the back-calculation plugin identifies the process areas that interact with infrastructure (elements at risk). That is, the resulting back calculation highlights the location of hazard starting zones and process paths associated with endangering infrastructure (see D.T3.2.1 for more information). These highlighted process areas were then used to clip a map of the forest cover extent, which results in areas defined as Direct Object Protection Forest (see D.T1.4.1 for definition). Therefore, for each PAR, maps of current forest areas and/or areas, which are officially defined as forest land are required (level 1 data; Table 1).

2) To quantify forests' protective effects against snow avalanches and rockfall, the forest plugin models the effect a forest has on the hazard process dependent on the forest's structure. Therefore, spatially-explicit forest structure information are needed for each PAR, which were combined to estimate the Forest Structure Index (FSI; see D.T3.2.1 for details), and to create a 10-m FSI raster, which is used as input to the forest plugin. The FSI quantifies the structure of the forested area with regards to the forest's ability to impact the runout velocity and distance of a hazard process, and ranges between 0 and 1, where 1 is the most effective forest with respect to natural hazard protection and 0 is a non-forested area. Level 2 and 3 data were applied to create the hazard specific FSI raster files based on information on forest types and, if available, on more detailed information on forest structure, e.g. in terms of canopy cover or stem density.

Table 1. Forest data levels and descriptions differentiated by natural hazard process, which were used to determine forest's direct object protective functions and effects by applying the Flow-py model.

		Natural hazard process		
Data level	Description	Snow avalanche	Rockfall	Shallow landslide
Level 1	Forest cover extent	Forest YES/NO	Forest YES/NO	Forest YES/NO
Level 2	Forest type	- Evergreen coniferous forest; - Deciduous and mixed forest*; - Krummholz, bushes and shrubs	- Coppice, broadleaved and mixed forest; - Coniferous forest - Bushes and shrubs	NA
Level 3	Forest structure and measurements	- Percentage of canopy cover	- Stem density; - Top height	NA

*including larch-dominated forest

Forest types that were classified by dominant tree species and distinguished to have different effects on snow avalanche release and runout, and rockfall runout are also listed in Table 1. For shallow landslides, a quantification of forest's protective effect based on differences in forest structure was considered inappropriate, because many stabilizing hydrological and mechanical effects of trees are particularly site specific and change in space and time (e.g. Moos et al., 2016; Schmaltz et al., 2019), which could not be addressed with the applied regional modeling approach and the available input data (see D.T3.2.1 for details). Therefore, we used only level 1 data and assumed that a forest located on a landslide-prone slope is more "relevant" compared to a forest on unsusceptible terrain.

In the following subchapters, we describe how the forest cover extent was retrieved (level 1 data), how forest types were classified in terms of their protective capacity against snow avalanches and rockfall (level 2 data), and which level 3 data was used and processed for each PAR based on the available input data (Table 2).

Table 2. Overview of the forest data sets that were submitted and used to produce input data sets for modeling direct object protection forests and their protective effects for each PAR.

Data set name	Data description	Data status (year)	Data source	Notes
PAR1 Val Ferret, Italy				
forest_cover_1.shp	27 forest types based on the new forest map of the Aosta Valley Autonomous Region	2011	Aosta Valley Autonomous Region (http://geoportale.regione.vda.it/download/)	See Camerano et. al (2007) for explanation and interpretation of forest types
PAR2 Kranjska Gora, Slovenia				
stands_2.shp	Contains several forest parameters, e.g. volume per ha, volume of conifer tree species per ha, volume of broadleaved tree species per ha, mean stand height, percentage of evergreen trees, percentage of deciduous trees, percentage of coniferous trees, percentage of broadleaved trees, percentage of canopy cover	2016	SFS	data were collected with terrestrial and remote sensing methods between 2010 and 2017, but mostly in 2016
PAR3 Oberammergau/Ettal, Germany				
Waldfläche_3.shp	Forest land		LWF	Retrieved from land use map
WINALP_Waldtypen_3.shp	Forest typification based on modeled distribution of main forest types	2011	LWF	From WINALP "Waldinformationssystem Nordalpen"
PAR4 Parc des Baronnies, France				
BD_Foret_V2_Dep005_2014.shp, BD_Foret_V2_Dep026_2014.shp	Information about 32 forest types	2014	National forest inventory BD Forêt version 2 (https://inventaire-forestier.ign.fr/spip.php?article646)	Two files for Dèpartements 5 (Hautes-Alpes) and 26 (Drôme)
departement_05.shp, departement_26.shp	Forest divided into “forêts de feuillus” (broadleaved forest) and “forêts de conifèrs” (coniferous forest).	2019	CES OSO land use map of 2019 (http://osr-cesbio.ups-tlse.fr/~oso/)	Two files for Dèpartements 5 (Hautes-Alpes) and 26 (Drôme)
ForestTypes_polygon.shp	Forest typification based on modeled distribution of main forest types	2011	Autonome Provinz Bozen/Provincia autonoma di Bolzano (https://geoportal.buergernetz.bz.it/geodaten.asp)	
liss13_5.shp	Land use map	2013	Autonome Provinz Bozen/Provincia autonoma di Bolzano, 28.0.1 Landeskartographie und Koordination der Geodaten	From LISS - Land Use Information System South Tyrol
PAR6 Vals/Gries am Brenner, Austria				

FP_AS_Vals_Brenner_DIM_TT15.shp	Forest parameters calculated from segregated orthophotos	2014-2016	Amt der Tiroler Landesregierung, Abteilung Waldschutz	Infrastructure and non-forested areas are excluded
Waldtypisierung.shp	Forest typification based on modeled distribution of main forest types	2014	Amt der Tiroler Landesregierung, Abteilung Waldschutz	
Gries_A_Br_Nutzung.shp; Vals_Nutzung.shp	Land use map	2019	Amt der Tiroler Landesregierung, Abteilung Waldschutz	Two files for municipalities Gries am Brenner and Vals

Note: Shown are only the data sets that were actually used and not all data sets provided by the institutions linked to the PARs.

2.2 PAR1 Val Ferret, Italy

The data set “forest_cover_1.shp” provided by the GR4A partner SFM (Table 2) was used for both to represent the current forest cover (level 1 data) and to classify the forest types (level 2 data) by the attribute “TIPIFORE” into forest types needed for Flow-py simulations of forest’s protective effects against avalanches and rockfall (Table 3). No level 3 data was available for PAR1.

The “forest_cover_1.shp” file is a clipping of the forest typology of the Aosta Valley Autonomous Region, which has been elaborated, developed and revised since 1998 in the context of various Interreg projects. The final product "I tipi forestali della Valle d’Aosta" (Camerano et al., 2007) distinguishes 15 forest categories and 49 forest types. Based on that and as result of the project “Renerfor” the new forest map of the Aosta Valley Autonomous Region was created in 2011 on a scale of 1:25.000 (survey scale 1:10.000; minimum mapping unit 1.000 m^2). This forest map now distinguishes 21 forest categories (14 broadleaved, 6 coniferous and 1 mixed), and 95 forest types. Each forest type, subtype and variant is described by an alpha-numeric code. Within PAR1, 27 forest types can be found, which are summarized in Table 3.

Table 3. Forest types (CODE and TIPIFORE) of 2011 forest map of the Aosta Valley Autonomous Region found within PAR1 Val Ferret, Italy, which were used to classify forest types for modeling forest’s protective effects against avalanches and rockfall in PAR1 Val Ferret, Italy.

Attribute		Forest type specific for natural hazard process:	
CODE	TIPIFORE	Snow avalanche	Rockfall
AF50X	Mountainous maple-ash pioneer forest	Deciduous and mixed	Coppice, broadleaved and mixed
AN21X	Alder forest subtype slope	Deciduous and mixed	Coniferous*
AN22A	Alder forest subtype riparian variant maple and ash	Deciduous and mixed	Coppice, broadleaved and mixed
BS20X	Mountainous birch forest	Krummholz, bushes and shrubs	Coppice, broadleaved and mixed
BS32X	Ruderal shrub subtype mountainous	Krummholz, bushes and shrubs	Bushes and shrubs
BS80X	Rocky ruderal shrub	Krummholz, bushes and shrubs	Bushes and shrubs
LC20A	Mountainous larch forest variant mixed broadleaved forest	Deciduous and mixed	Coniferous
LC20C	Mountainous larch forest variant *Picea*	Deciduous and mixed	Coniferous
LC20X	Mountainous larch forest	Deciduous and mixed	Coniferous
LC32X	Meso-xerophile subalpine larch forest subtype acidophilus	Deciduous and mixed	Coniferous
LC40X	Larch forest with tall herbs	Deciduous and mixed	Coniferous
LC51B	Larch-arolla pine forest on *Rhododendro-Vaccinion* subtype inferior variant *Picea*	Deciduous and mixed	Coniferous
LC51E	Larch-arolla pine forest on *Rhododendro-Vaccinion* subtype inferior variant *Larix*	Deciduous and mixed	Coniferous
LC51X	Larch-arolla pine forest on *Rhododendro-Vaccinion* subtype inferior	Deciduous and mixed	Coniferous
LC52B	Larch-arolla pine forest on *Rhododendro-Vaccinion* subtype superior variant *Larix*	Deciduous and mixed	Coniferous
LC52X	Larch-arolla pine forest on *Rhododendro-Vaccinion* subtype superior	Deciduous and mixed	Coniferous
LC60A	Boulder field larch forest variant *Picea*	Deciduous and mixed	Coniferous
LC60X	Boulder field larch forest	Deciduous and mixed	Coniferous
LC80X	Pebble riverbed larch forest	Deciduous and mixed	Coniferous
OV31X	Green alder forest subtype primary	Deciduous and mixed	Coniferous*

OV32A	Green alder forest subtype ruderal variant *Larix*	Deciduous and mixed	Coniferous*
PE30B	Endalpic mountainous spruce forest variant ruderal broadleaved forest	Deciduous and mixed	Coniferous
PE30D	Endalpic mountainous spruce forest variant *Larix*	Deciduous and mixed	Coniferous
PE50A	Meso-xerophile spruce forest variant *Larix*	Deciduous and mixed	Coniferous
PN11A	Erect *Pinus uncinata* forest subtype acidophilus variant *Larix*	Krummholz, bushes and shrubs	Bushes and shrubs
PN23X	Procumbent *Pinus uncinata* forest subtype acidophilus	Krummholz, bushes and shrubs	Bushes and shrubs
SP10B	Riparian *Salix* shrub variant *Salix daphnoides*	Krummholz, bushes and shrubs	Bushes and shrubs

*The (green) alder forests were classified as "Coniferous" forest since this forest type is assigned a lower FSI compared to "Coppice, broadleaved and mixed" forest. Most alpine (green) alder forests are located in highly frequented avalanche paths or gullies and therefore often stay in a shrub-like development stage or have thin stems and do not have the same protective capacity as an average "Coppice, broadleaved and mixed" forest.

2.3 PAR2 Kranjska Gora, Slovenia

The data set "stands_2.shp" was provided by the GR4A partners UL and SFS, which contains a list of attributes describing level 1, level 2, and level 3 forest data. The data summarized in this data set were collected by the SFS with terrestrial and remote sensing methods (orthophotography, lidar) between 2010 and 2017 (orthophotos: 2016, 2017; lidar: 2014, 2015; forest mensuration: mostly 2016 and 2017, but also 2010 and 2014).

To retrieve the current forest cover (level 1 data), all polygons in "stands_2.shp" (which are, based on a land use classification, considered forest) were used to create a 10-m forest cover raster.

Level 2 data was available as attributes:
- per_eve (percentage of evergreen trees of the total growing stock),
- per_dec (percentage of deciduous trees of the total growing stock,
- per_con (percentage of coniferous trees including larch of the total growing stock) and,
- per_bro (percentage of broadleaved trees of the total growing stock)

We classified forest types based on their protective capacity against avalanche as follows:
- Evergreen coniferous forest, if per_eve ≥ 75
- Deciduous and mixed forest, if per_eve < 75
- Krummholz, bushes and shrubs, if per_eve AND per_dec = 0

The level 3 data to be included in the FSI calculation for avalanche simulations with the forest plugin was labelled by attribute percent_cc, which is the percentage of canopy covered area (derived from a lidar-based canopy height model [CHM] with canopy heights between 5 and 50 m and a resolution of 1 × 1m) of the total stand area. Features were converted to a 10-m raster with the percent_cc value.

Rockfall forest types were classified based on the following attributes and thresholds:
- Coppice, broadleaved and mixed forest, if per_con ≤ 75
- Coniferous forest, if per_con > 75
- Bushes and shrubs, if per_con AND per_bro = 0

The level 3 data attribute that was included in the FSI calculation for rockfall simulations is s_height (stand height), which represents the average tree height of a stand. Tree heights to calculate the stand height were obtained from the CHM. Only the heights that were located within the spatial extent of forest cover, which is based on a land use classification were included.

2.4 PAR3 Oberammergau/Ettal, Germany

Two forest data sets were submitted by the GR4A partner LWF characterizing forest cover (level 1 data; data set “3_waldflaeche.shp”) and forest types (level 2 data; data set “3_winalp_waldtypenk.shp”) of PAR3; no level 3 data was available. The “3_winalp_waldtypenk.shp” data set is a clipping of a product that was produced in 2011 within the Interreg project "Waldinformationssystem Nordalpen" (forest information system Northern Alps, WINALP) project. The spatial data set of forest types is a result of combining information on location, climate, geology and soil, and linking it to site and vegetation surveys.

To create the 10-m forest cover extent (forest YES/NO) raster, we selected polygons with the attribute “obtyp” = Wald from the “3_waldflaeche.shp” data set (level 1 data) and converted the selected features to a raster.

The data set “3_winalp_waldtypenk.shp” was used to classify forest types with different effects on snow avalanches and rockfall runouts based on the attribute “baumart” (tree species; see Table 4), and converted to two 10-m raster files for avalanches and rockfall. The forest type rasters were masked with the 10-m forest cover extent raster (see above). This step was included to represent the current state of the forest extent in the simulations since “3_winalp_waldtypenk.shp” is based on modeled forest types. We assigned the lowest possible FSI-value, which translates to bushes and shrubs to cells with the value “forest YES” in the forest cover extent raster but no assigned forest type.

Table 4. Attribute and description of the data set 3_winalp_waldtypenk.shp used to classify forest types for modeling forest’s protective effects against avalanches and rockfall in PAR3 Oberammergau/Ettal, Germany.

Attribute		Forest type specific for natural hazard process:	
“baumart”	Description/tree species	Snow avalanche	Rockfall
Fi	spruce-dominated	Evergreen coniferous	Coniferous forest
FT	spruce-fir forest	Evergreen coniferous*	Coniferous forest*
FTB	spruce-fir-beech forest	Evergreen coniferous*	Coniferous forest*
Ta	fir-spruce forest	Evergreen coniferous	Coniferous forest
Ah	Hardwood forest	Deciduous and mixed	Coppice, broadleaved and mixed
Es	riparian forest	Deciduous and mixed	Coppice, broadleaved and mixed
Lat	krummholz	Krummholz, bushes and shrubs	Bushes and shrubs
Wei	willow	Krummholz, bushes and shrubs	Bushes and shrubs

*Although FT and FTB are mixed type forests, additional information and field surveys show that these forests are largely dominated by spruce.

2.5 PAR4 Parc des Baronnies; France

Level 1 data was submitted by the GR4A partner INRAE as a the CES OSO land use map of 2019 in two separate files for the Dèpartements 5 (Hautes-Alpes; “departement_05.shp”) and 26 (Drôme; “departement_26.shp”) covering eastern and western parts of PAR4. The OSO land use map in vector format is produced annually based on images from Sentinel-2 satellites with a minimum area for sampling units of 0.1 ha, which are derived from a 20 m raster. Forest land is divided into "forêts de feuillus" (broadleaved forest, numeric code 31) and "forêts de conifèrs" (coniferous forest, numeric code 32). We therefore combined both data sets and used the attribute "Classe" to extract forested areas (Classe = 31 AND Classe = 32), and converted the selected features to a 10-m resolution forest cover raster.

Level 2 data was provided in form of the two data sets "BD_Foret_V2_Dep026_2014.shp" and "BD_Foret_V2_Dep005_2014.shp", which are parts of the national forest inventory BD Forêt version 2. These maps contain information about 32 forest types of areas (mapping units) ≥ 0.5 ha. Spatial information about coppice stands were extracted from the map products of BD Fôret version 1 (mapping units ≥ 2.25 ha; valid until 2006), and added to the current forest type map (BD Forêt version 2) since this forest type was not included in version 2, but is of great importance for rockfall protection in PAR4. We combined the two data sets for the Dèpartements 5 and 26, and used the attribute "ESSENCE" (tree species) to classify forest types for rockfall simulations with Flow-py and the forest plugin (Table 5). Avalanche simulations were not conducted for PAR4.

Table 5. Values and descriptions of the attribute "ESSENCE" of the data sets "BD_Foret_V2_Dep026_2014.shp" and "BD_Foret_V2_Dep005_2014.shp", which was used to classify forest types for modeling forest's protective effects against rockfall in PAR4 Parc des Baronnies, France.

"Essence"	Description	Forest type
Chênes décidus	oak/deciduous	Coppice, broadleaved and mixed
Conifères	conifers	Coniferous forest
Douglas	Douglas fir	Coniferous forest
Feuillus	broadleaves	Coppice, broadleaved and mixed
Hêtre	beech	Coppice, broadleaved and mixed
Mélèze	larch	Coniferous forest
Mixte	mixed	Coppice, broadleaved and mixed
NC	shrubland	Bushes and shrubs
NR	open forest without closed canopy	Bushes and shrubs
Peuplier	poplar	Bushes and shrubs*
Pin à crochets, pin cembro	mountain pine, Swiss stone pine	Coniferous forest
Pin autre	other pine	Coniferous forest
Pin laricio, pin noir	Austrian pine	Coniferous forest
Pin sylvestre	Scots pine	Coniferous forest
Pins mélangés	mixed pine	Coniferous forest
Sapin, épicéa	fir, spruce	Coniferous forest

*Although poplars are hardwoods and broadleaved trees, we classified them as "bushes and shrubs" since they are cultivated in fast-growing energy wood plantations with thin stems and are harvested after a few years- They do not have the protective capacity of an average "Coppice, broadleaved and mixed" forest against rockfall.

2.6 PAR5 Southern Wipptal, Italy

For PAR5 Southern Wipptal, one data set to provide level 1 data ("liss13_5.shp") and one data set containing level 2 data ("ForestTypes_polygon.shp") were submitted by the GR4A partner Eurac Research. Level 3 data was not available for PAR5.

To create a raster of the forest cover extent for defining forest areas with a direct object protective function, polygons with the attribute LANDUSE_DE = Wald (numeric code 5) were selected from the land use "liss13_5.shp" data set and converted into a raster file. LISS is the Land Use Information System South Tyrol developed in 2013, which provides up-to-date land cover and land use information based on satellite images (RapidEye, WorldView 2), orthophotos and other available geodata, e.g. results from research projects.

The file “ForestTypes_polygons_clip.shp” is a clipping of the forest typification (scale 1:25.000; published in 2011) data set that is provided by the Autonome Provinz Bozen/Provincia autonoma di Bolzano through their online geoportal “Südtiroler Bürgernetz” (https://geoportal.buergernetz.bz.it/geodaten.asp). We selected the attribute “WGRU_BEZ_D” and combined the forest types listed under this attribute to the forest types needed for modeling forest’s effects against avalanches and rockfall (Table 6), and converted the newly classified features into two 10-m raster files.

Table 6. Attribute and description of the data set ForestTypes_polygon_clip.shp that was used to classify forest types for modeling forest’s protective effects against avalanches and rockfall in PAR5 Southern Wipptal, Italy.

Attribute "WGRU_BEZ_D"	Description/dominant tree species	Forest type specific for natural hazard process: Snow avalanche	Rockfall
Fichten-Tannenwälder	spruce-fir forest	Evergreen coniferous	Coniferous forest
Kiefernwälder	pine forest	Evergreen coniferous	Coniferous forest
Montane Fichtenwälder	montane spruce forest	Evergreen coniferous*	Coniferous forest*
Subalpine Fichtenwälder	subalpine spruce forest	Evergreen coniferous	Coniferous forest
Auwälder	riparian forest	Deciduous and mixed	Bushes and shrubs
Eichen-Kiefernwälder	oak-pine forest	Deciduous and mixed	Coppice, broadleaved and mixed
Eichenwälder	oak forest	Deciduous and mixed	Coppice, broadleaved and mixed
Lärchen-Zirbenwälder	larch-Swiss stone pine forest	Deciduous and mixed	Coniferous forest
Lärchenwälder	larch forest	Deciduous and mixed	Coniferous forest
Laubwälder	broadleaved forest	Deciduous and mixed	Coppice, broadleaved and mixed
Grünerlen- und Latschenbuschwälder	krummholz and bushes	Krummholz, bushes and shrubs	Bushes and shrubs

We masked the two forest type rasters with the 10-m forest cover extent raster (see above) to represent the current state of the forest extent in the simulations since “ForestTypes_polygons_clip.shp” is based on modeled forest types. If a cell classified as forest overlapped with a cell with no forest type information, then we classified this cell as “Bushes and shrubs” with the lowest possible FSI-value.

2.7 PAR6 Vals/Gries am Brenner, Austria

To create a raster of the forest cover extent (level 1 data), we used the newest land use data set (split in the two files “Gries_A_Br_Nutzung.shp” and “Vals_Nutzung.shp”) from 2019, which was provided by the Abteilung Waldschutz of the Amt der Tiroler Landesregierung. This data set is not released yet, but could be used in the project GR4A by the BFW. Therefore, we combined both files, selected polygons with the attribute Nutzungsgr = Wald and converted them to a 10-m resolution raster.

The forest typification (“Waldtypisierung.shp”) Tirol contains forest types (level 2 data), those distributions were modeled based on spatially explicit terrain, geology, climate and forest data that were combined with field surveys and measurements and adjusted with knowledge from literature, locals and experts. This map comprehensively represents and provides information on existing forest types at a scale of 1:25.000 with an estimated accuracy of 75% (+/- 5%)

compared to terrestrial mapping; only main forest sites are included. The data set can be viewed in the geoportal of the state of Tyrol (tiris, Tiroler Rauminformationssystem https://maps.tirol.gv.at), and was provided by the Amt der Tiroler Landesregierung, Abteilung Waldschutz. We selected and combined forest types that are listed under the attribute "NAME" to the forest types needed for modeling forest's effects against avalanches (Table 7) and rockfall (Table 8). Based on our simplified classification and associated values, features were converted to two 10-m forest type raster files.

In addition to level 1 and 2 forest data, also level 3 data was available for PAR6. The data set "FP_AS_Vals_Brenner_DIM_TT15.shp" (provided by the Tiroler Landesregierung, Abteilung Waldschutz) contains forest parameters, which were calculated based on segmented orthophotos from flights between 2014-2016. For the segmentation, a minimum height of 3 m and a minimum stand area of 300 m² were defined as thresholds. We used the attributes "DG" (percentage of canopy cover), "TC_HA" (stems per ha) and "MH" (mean tree height) to adjust the forest type raster files (level 2 data) producing 10-m FSI raster files (see D.T3.2.1), which are used by Flow-py and the forest plugin to model forest's protective effect against avalanches and rockfall. The forest area of the data set "FP_AS_Vals_Brenner_DIM_TT15.shp" was applied to mask the final FSI raster files.

Table 7. Classification of forest types by the attribute "NAME" of the data set Waldtypisierung.shp into forest types for modeling forest's protective effects against avalanches in PAR6 Vals/Gries am Brenner, Austria.

Evergreen coniferous	Deciduous and mixed	Krummholz, bushes and shrubs
Armer Silikat-Fichten-Tannenwald	Auflagehumus-Karbonat-Lärchen-Zirbenwald	Latschen, Grünerlen, Laubholz-Buschwälder,
Frischer Karbonat-Fichten-Tannenwald	Frischer basischer Grünerlen-(Zirben-)Lärchenwald	Verbuschende Flächen
Frischer Silikat-Fichten-Tannenwald		Lavendelweidenau
Kühler basischer Steilhang-(Lärchen-)Fichtenwald	Kühler Karbonat-Steilhang-Lärchenwald	
Lawinar-Silikat-(Grünerlen-)Lärchen-Fichtenwald	Kühler Steilhang-Silikat-(Grünerlen-Zirben-)Lärchenwald	
Montaner armer Karbonat-Fichten-Tannenwald		
Montaner armer Karbonat-Lärchen-Fichtenwald	Lawinarer Grünerlen-Lärchen-(Zirben-)Wald	
Montaner armer Silikat-(Lärchen-)Fichtenwald	Montane Grauerlenau	
Montaner frischer basischer Fichtenwald	Trockener basischer Wacholder-(Fichten-)Lärchenwald	
Montaner frischer Silikat-(Lärchen-)Fichtenwald		
Montaner Karbonat-Fels-Kiefernwald	Trockener Karbonat-Latschen-(Zirben-)Lärchenwald	
Montaner kühler Silikat-Steilhang-Lärchen-Fichtenwald		
Montaner trockener Silikat-(Kiefern-)Fichtenwald	Trockener Silikat-Fels-Lärchen-Zirbenwald	
Montaner warmer Karbonat-Fichtenwald		
Montaner warmer Silikat-(Lärchen-)Fichtenwald		
Reicher basischer Fichten-Tannenwald		
Reicher Silikat-Fichten-Tannenwald		
Subalpiner armer Silikat-(Lärchen-)Fichtenwald		
Subalpiner Auflagehumus-Karbonat-Lärchen-Fichtenwald		
Subalpiner basischer Lärchen-Fichtenwald		
Subalpiner feuchter basischer (Grünerlen-)Lärchen-Fichtenwald		
Subalpiner frischer Karbonat-Fichtenwald		
Subalpiner frischer Silikat-Fichtenwald		
Subalpiner kühler Silikat-Steilhang-(Grünerlen-Lärchen-)Fichtenwald		
Subalpiner Silikat-Fichten-Blockwald		
Subalpiner trockener Karbonat-(Lärchen-)Fichtenwald		
Subalpiner trockener Silikat-Lärchen-Fichtenwald		
Subalpiner warmer Silikat-Lärchen-Fichtenwald		
Trockener Karbonat-Kiefernwald		
Warmer basischer (Lärchen-)Fichtenwald		
Silikat-Vogelbeeren-Birken-Zirben-Blockwald		
Warmer Silikat-Lärchen-Zirbenwald		
Armer Silikat-Lärchen-Zirbenwald		

Table 8. Classification of forest types by the attribute "NAME" of the data set Waldtypisierung.shp into forest types for modeling forest's protective effects against rockfall in PAR6 Vals/Gries am Brenner, Austria.

Coppice, broadleaved and mixed	Coniferous forest	Bushes and shrubs
Montane Grauerlenau	Armer Silikat-Fichten-Tannenwald	Latschen, Grünerlen, Laubholz-Buschwälder,
	Armer Silikat-Lärchen-Zirbenwald	Verbuschende Flächen
	Auflagehumus-Karbonat-Lärchen-Zirbenwald	Lavendelweidenau
	Frischer basischer Grünerlen-(Zirben-)Lärchenwald	
	Frischer Karbonat-Fichten-Tannenwald	
	Frischer Silikat-Fichten-Tannenwald	
	Kühler basischer Steilhang-(Lärchen-)Fichtenwald	
	Kühler Karbonat-Steilhang-Lärchenwald	
	Kühler Steilhang-Silikat-(Grünerlen-Zirben-)Lärchenwald	
	Lawinarer Grünerlen-Lärchen-(Zirben-)Wald	
	Lawinar-Silikat-(Grünerlen-)Lärchen-Fichtenwald	
	Montaner armer Karbonat-Fichten-Tannenwald	
	Montaner armer Karbonat-Lärchen-Fichtenwald	
	Montaner armer Silikat-(Lärchen-)Fichtenwald	
	Montaner frischer basischer Fichtenwald	
	Montaner frischer Silikat-(Lärchen-)Fichtenwald	
	Montaner kühler Silikat-Steilhang-Lärchen-Fichtenwald	
	Montaner Karbonat-Fels-Kiefernwald	
	Montaner trockener Silikat-(Kiefern-)Fichtenwald	
	Montaner warmer Karbonat-Fichtenwald	
	Montaner warmer Silikat-(Lärchen-)Fichtenwald	
	Reicher basischer Fichten-Tannenwald	
	Reicher Silikat-Fichten-Tannenwald	
	Silikat-Vogelbeeren-Birken-Zirben-Blockwald	
	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	
	Subalpiner Auflagehumus-Karbonat-Lärchen-Fichtenwald	
	Subalpiner basischer Lärchen-Fichtenwald	
	Subalpiner feuchter basischer (Grünerlen-)Lärchen-Fichtenwald	
	Subalpiner frischer Karbonat-Fichtenwald	
	Subalpiner frischer Silikat-Fichtenwald	
	Subalpiner kühler Silikat-Steilhang-(Grünerlen-Lärchen-)Fichtenwald	
	Subalpiner Silikat-Fichten-Blockwald	
	Subalpiner trockener Karbonat-(Lärchen-)Fichtenwald	
	Subalpiner trockener Silikat-Lärchen-Fichtenwald	
	Subalpiner warmer Silikat-Lärchen-Fichtenwald	
	Trockener basischer Wacholder-(Fichten-)Lärchenwald	
	Trockener Karbonat-Kiefernwald	
	Trockener Karbonat-Latschen-(Zirben-)Lärchenwald	
	Trockener Silikat-Fels-Lärchen-Zirbenwald	
	Warmer basischer (Lärchen-)Fichtenwald	
	Warmer Silikat-Lärchen-Zirbenwald	

3 Forest data for modeling impacts of climate change on protection forests

3.1 Overview of required basic, forest and site data

The tree growth simulator CALDIS (Kindermann, 2010; Ledermann et al., 2017) was fed with (local) temperature and precipitation scenarios, i.e. bias-corrected CC projections (GCM-RCM projections provided by the EURO-CORDEX initiative), to derive information on how CC may affect the development of protection forests in the different PARs (for details and results see D.T1.1.1). Besides climate parameters associated with CC scenarios, CALDIS therefore needs local forest parameters (i.e. single stem parameters), and site conditions to derive associated forest development scenarios in terms of basal area (i.e. the average amount of an area occupied by tree stems) and total stem volume.

For five of the six GR4A PARs, no more than 20 data records that included basic, forest and site parameters were compiled from existing forest inventories and permanent forest plots, or collected in the field using angle-count sampling (Bitterlich, 1948), or fixed-radius sampling designs. Data records represent mainly forests with a protective function (see Appendix A for detailed instructions on data collection).

Each protection forest data record must include:

<u>Basic information:</u>

- ID (each record of forest and site parameters has one unique ID that links basic, forest and site parameters)
- Sampling date (DD.MM.YY)
- Plot/stand size (ha)
- Elevation (m)
- Position (Lat/Long)
- Growth region

<u>Forest and vegetation parameters for each ID/record:</u>

- Vegetation type (according to the ANFI)
- Tree species (Species code following EN 13556)
- Diameter at breast height (dbh [cm])
- Tree height (m)
- Crown height (height up to the beginning of the living crown [m])
- Number of stems per ha

<u>Site parameters:</u>

- Slope angle (°)
- Exposition (°)
- Relief: position of the stand on a slope/in the landscape in 8 classes:
    - 1 upper slope/convex slope
    - 2 middle slope
    - 3 lower slope/concave slope
    - 4 trench
    - 5 valley bottom
    - 6 flat
    - 7 depression
    - 8 stream

- Soil type (according to the ANFI)
- Water balance/hydrological regime (estimated in 5 classes):
    - 1 dry
    - 2 moderately fresh
    - 3 fresh
    - 4 very fresh
    - 5 wet
- Soil depth (2 classes):
    - 1, 0-30 cm
    - 2, >30 cm

In the following subchapters, we summarize how forest data was collected for each PAR and list the basic, forest and site parameters, which were used as input data and, therefore, starting point for the CALDIS simulations.

3.2 PAR1 Val Ferret, Italy

In PAR1, the required forest data was collected in July 2019 using angle-count sampling (Bitterlich, 1948). Gathered basic information, and forest and site parameters are listed in Table 9 (basic), Table 10 (forest), and Table 11 (site).

Table 9. PAR1 Val Ferret basic information and sampling locations of forest data records used for forest growth simulations under climate change scenarios.

ID	Sampling date (DD.MM.YY)	Elevation (m)	Latitude	Longtitude	Growth region
IT01001	17.07.19	1474	45,82072	6,97132	Northern Graie Alps
IT01002	17.07.19	1492	45,82178	6,97205	Northern Graie Alps
IT01003	17.07.19	1538	45,8246	6,97748	Northern Graie Alps
IT01004	17.07.19	1501	45,82414	6,97652	Northern Graie Alps
IT01005	17.07.19	1501	45,82332	6,97532	Northern Graie Alps
IT02001	18.07.19	1649	45,84305	7,009	Northern Graie Alps
IT02002	18.07.19	1663	45,84391	7,00835	Northern Graie Alps
IT02003	18.07.19	1695	45,84478	7,00814	Northern Graie Alps
IT02004	18.07.19	1704	45,84566	7,00927	Northern Graie Alps
IT02005	18.07.19	1689	45,84607	7,00994	Northern Graie Alps
IT03001	18.07.19	1655	45,84188	7,0027	Northern Graie Alps
IT03002	18.07.19	1685	45,84252	7,00264	Northern Graie Alps
IT03003	18.07.19	1720	45,84299	7,00223	Northern Graie Alps
IT03004	18.07.19	1767	45,8432	7,00062	Northern Graie Alps
IT04001	18.07.19	1777	45,84229	6,99794	Northern Graie Alps
IT04002	18.07.19	1735	45,84102	6,99789	Northern Graie Alps
IT04003	18.07.19	1687	45,84068	6,99888	Northern Graie Alps
IT05		1641	45,83548	6,98125	Northern Graie Alps
IT06		1953	45,83705	7,01365	Northern Graie Alps

Table 10. PAR1 Val Ferret vegetation types and forest parameters of forest data records used for forest growth simulations under climate change scenarios.

ID	Vegetation type	Main tree species[1]	Mean dbh[2] (cm)	Mean height (m)	Stems/ha
IT01001	Subalpine spruce forest	BTXX, LADC, PCAB	22	12	734
IT01002	Subalpine spruce forest	LADC, PCAB	22	18	982
IT01003	Subalpine spruce forest	LADC, PCAB	21	15	627

IT01004	Subalpine spruce forest	LADC, PCAB	22	16	892
IT01005	Subalpine spruce forest	LADC, PCAB	26	13	919
IT02001	Subalpine larch forest	LADC	25	14	1278
IT02002	Subalpine larch forest	LADC	21	15	1221
IT02003	Subalpine larch forest	LADC	17	11	1376
IT02004	Subalpine larch forest	LADC	26	20	363
IT02005	Subalpine larch forest	LADC	40	18	395
IT03001	Subalpine larch forest	LADC, PCAB	23	16	1031
IT03002	Subalpine larch forest	LADC, PCAB	38	16	514
IT03003	Subalpine larch forest	LADC	35	22	628
IT03004	Subalpine larch forest	LADC	42	17	532
IT04001	Subalpine larch forest	LADC	67	27	200
IT04002	Subalpine larch forest	PCAB	40	19	409
IT04003	Subalpine larch forest	PCAB	51	23	394
IT05	Subalpine larch forest	LADC, PCAB	35	18	1329
IT06	Subalpine larch forest	LADC, PCAB	29	17	1250

[1]Species code following EN 13556 (https://de.wikipedia.org/wiki/DIN_EN_13556)

[2]dbh = diameter at breast height

Table 11. PAR1 Val Ferret site parameters of forest data records used for forest growth simulations under climate change scenarios.

ID	Slope (°)	Exposition (°)	Relief[1]	Soil type	Water balance[1]	Soil depth[1]
IT01001	34	307	2	Cambisols	3	2
IT01002	36	295	2	Cambisols	3	2
IT01003	49	320	2	Cambisols	3	2
IT01004	50	316	2	Cambisols	3	2
IT01005	43	312	2	Cambisols	3	2
IT02001	5	143	6	Cambisols	2	2
IT02002	8	178	3	Cambisols	2	2
IT02003	14	212	3	Cambisols	2	2
IT02004	15	144	3	Cambisols	2	2
IT02005	15	127	3	Cambisols	2	2
IT03001	9	91	3	Cambisols	2	2
IT03002	8	105	2	Cambisols	2	2
IT03003	24	145	2	Cambisols	2	2
IT03004	26	184	2	Cambisols	2	2
IT04001	17	111	6	Cambisols	2	2
IT04002	21	146	1	Cambisols	2	2
IT04003	14	149	2	Cambisols	2	2
IT05	21	160	2	Cambisols	2	2
IT06	35	283	2	Cambisols	3	2

[1]See Appendix A for definition of classes

3.3 PAR2 Kranjska Gora, Slovenia

Forest inventory data in Slovenia is collected periodically (every 5-10 years) by the SFS on a sampling grid of 4 × 4 km, and, to detect changes, annually on a 16 × 16 km grid. Each sampling cluster, which is located at a grid point consists of a concentric permanent sampling plot (CPSP) with four radii and 4 M6 plots (Figure 1).

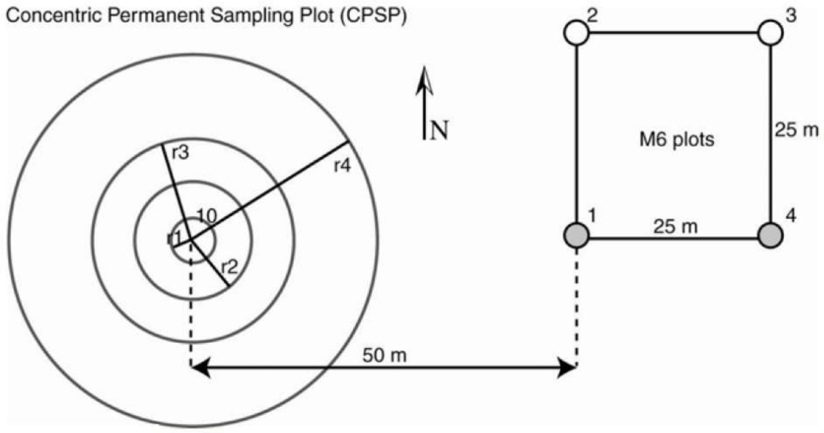

Figure 1. Sampling design of forest inventory sampling clusters in Slovenia. Source: Kusar and Simoncic (2010)

These forest inventory plots were supplemented with 1116 sampling plots that are located in PAR2. In these additional plots, small trees with 10 cm < dbh < 30 cm are measured within a radius of 7.98 m (area of 200 m^2); large trees with dbh > 30 cm are measured within a radius of 12.56 m (area 500 m^2). Tree height and crown height are not part of the forest inventory protocol; however, tree heights were estimated with local tariffs and crown heights with basic allometric equations (Pretzsch et al., 2002).

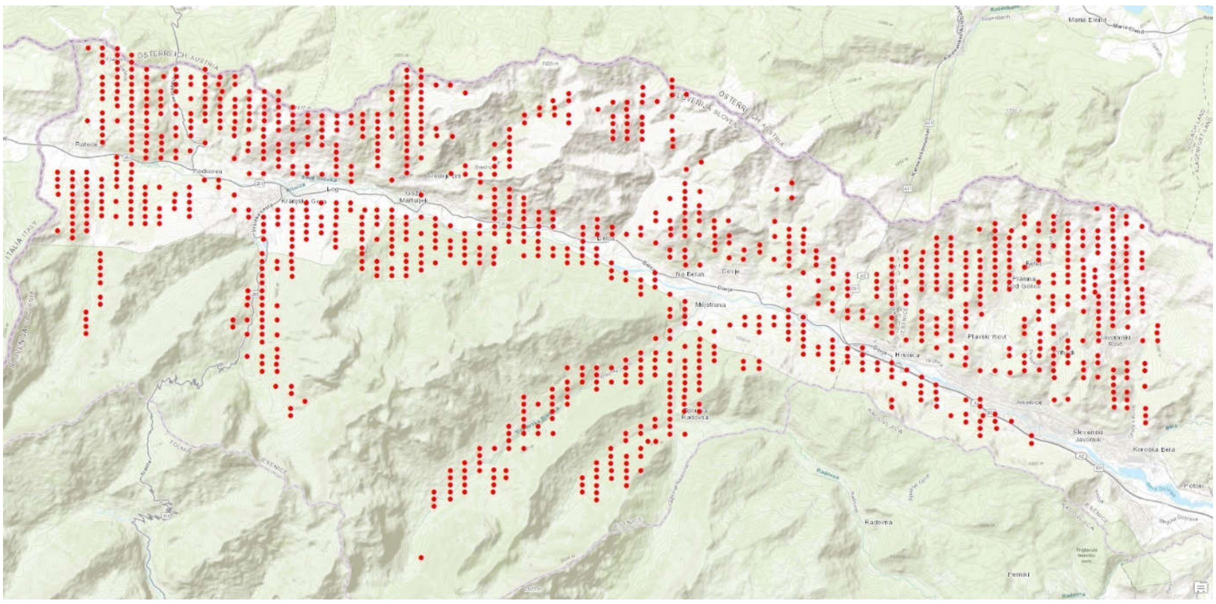

Figure 2. Forest inventory sampling plot locations (red) in PAR2 Kranjska Gora, Slovenia.

To gather the basic, forest and site information required for forest growth simulations with CALDIS, the GR4A partner SFS selected 14 forest inventory sampling plots, which were surveyed in September 2019 (Table 12, Table 13, and Table 14).

Table 12. PAR2 Kranjska Gora basic information and sampling locations of forest data records used for forest growth simulations under climate change scenarios.

ID	Sampling date (DD.MM.YY)	Elevation (m)	Latitude	Longtitude	Growth region
SI01	05.09.19	1000	46,5176	13,726	Karawanks
SI02	05.09.19	1300	46,5144	13,7574	Karawanks
SI03	05.09.19	900	46,4834	13,7212	Julian Alps
SI04	06.09.19	900	46,4906	13,7158	Julian Alps
SI05	06.09.19	900	46,4887	13,7106	Julian Alps
SI06	06.09.19	900	46,4979	13,7208	Karawanks
SI07	10.09.19	1000	46,4977	13,7314	Karawanks
SI08	10.09.19	1100	46,5017	13,7678	Karawanks
SI09	13.09.19	1200	46,4763	13,7164	Julian Alps
SI10	13.09.19	1000	46,4799	13,7317	Julian Alps
SI11	13.09.19	900	46,4819	13,7734	Julian Alps
SI12	13.09.19	1100	46,4964	13,7888	Karawanks
SI13	16.09.19	800	46,4805	13,8715	Karawanks
SI14	16.09.19	1100	46,3972	13,8356	Julian Alps

Table 13. PAR2 Kranjska Gora vegetation types and forest parameters of forest data records used for forest growth simulations under climate change scenarios.

ID	Vegetation type	Main tree species[1]	Mean dbh[2] (cm)	Mean height (m)	Stems/ha
SI01	Subalpine beech forest	FASY, PCAB	23	17	100
SI02	Alpine beech forest	FASY	28	19	83
SI03	Subalpine spruce forest	FASY, PCAB	32	26	35
SI04	Subalpine beech forest	FASY	32	24	25
SI05	Subalpine beech forest	FASY, PCAB	28	20	80
SI06	Secondary spruce forest	PCAB	52	33	43
SI07	Secondary spruce forest	FASY, PCAB	29	17	50
SI08	Secondary spruce forest	PCAB	39	25	35
SI09	Alpine beech forest	PCAB, FASY, ABAL	34	21	53
SI10	Secondary spruce forest	FASY	34	22	25
SI11	Secondary spruce forest	FASY, PCAB	24	20	30
SI12	Subalpine beech forest	FASY, PCAB	28	17	55
SI13	Mixed conifer forest	PNSY, PCAB	27	18	58
SI14	Alpine beech forest	FASY	31	22	50

[1]Species code following EN 13556 (https://de.wikipedia.org/wiki/DIN_EN_13556)

[2]dbh = diameter at breast height

Table 14. PAR2 Kranjska Gora site parameters of forest data records used for forest growth simulations under climate change scenarios.

ID	Slope (°)	Exposition (°)	Relief[1]	Soil type	Water balance[1]	Soil depth[1]
SI01	40	180	1	Dystric cambisol	3	2
SI02	32	270	1	Dystric cambisol	2	2
SI03	28	45	1	Rendzina on carbonate gravel	2	1
SI04	18	0	1	Dystric cambisol	3	1
SI05	40	315	1	Dystric cambisol	2	2
SI06	34	180	1	Rendzina on carbonate rock	3	2
SI07	26	180	1	Rendzina on carbonate rock	3	2
SI08	35	135	4	Dystric cambisol	3	2
SI09	36	90	1	Dystric cambisol	2	2
SI10	40	45	1	Rendzina on carbonate gravel	3	2
SI11	37	0	2	Rendzina on carbonate gravel	2	2
SI12	26	180	1	Dystric cambisol	1	1
SI13	16	180	2	Rendzina on carbonate gravel	2	1
SI14	26	45	3	Rendzina on carbonate gravel	2	1

3.4 PAR3 Oberammergau/Ettal, Germany

Basic information, and forest and site parameters that are required for forest growth simulations with CALDIS were collected in PAR3 in August 2019 using angle-count sampling (Bitterlich, 1948). The 20 sampling points were evenly distributed over the PAR area and chosen because of their location in forests with a protective or recreational function, which is of particular interest in PAR3 (Figure 3).

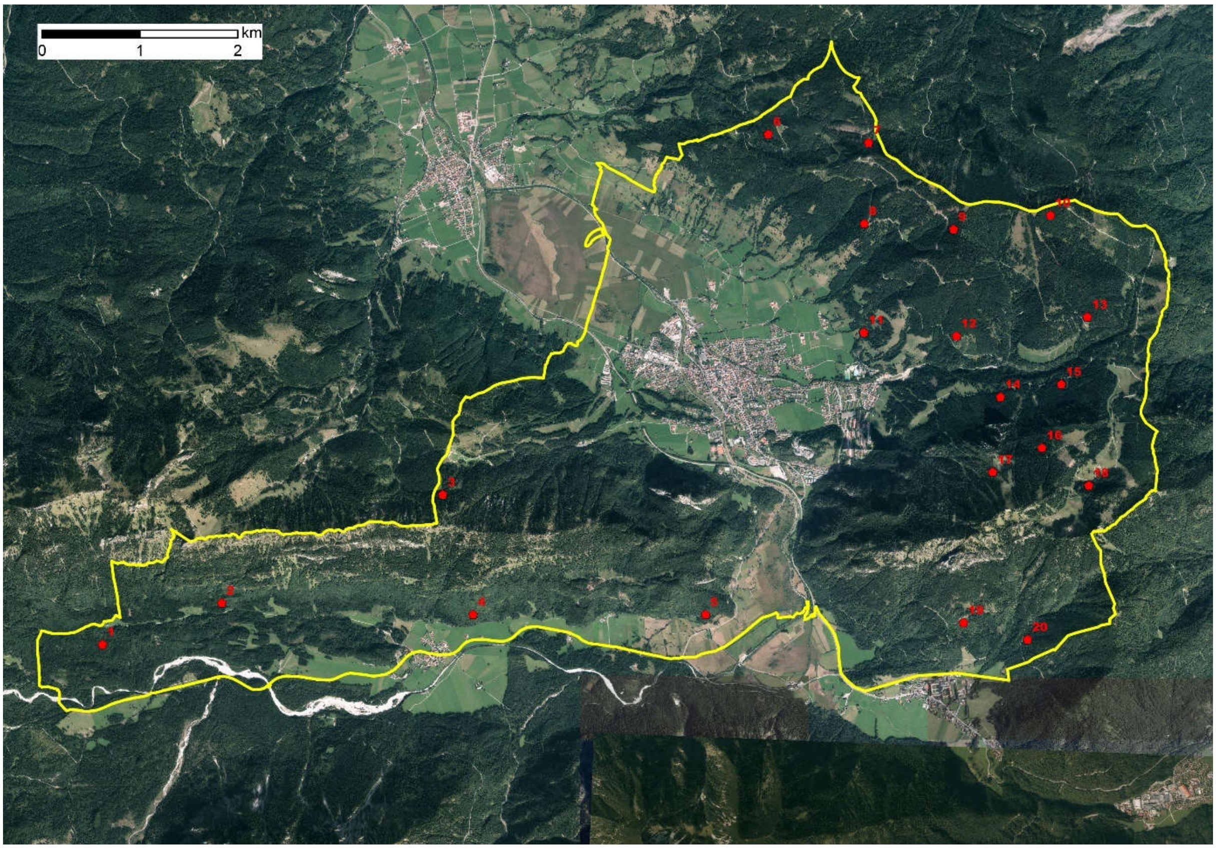

Figure 3. Sampling locations of 20 data records in PAR3 Oberammergau/Ettal, Germany (red), which included basic, forest and site parameters required for forest growth simulations under climate change scenarios; PAR boundary in yellow.

Submitted data records are summarized for basic information in Table 15, vegetation and forest parameters in Table 16, and site characteristics in Table 17.

Table 15. PAR3 Oberammergau/Ettal basic information and sampling locations of forest data records used for forest growth simulations under climate change scenarios.

ID	Sampling date (DD.MM.YY)	Elevation (m)	Latitude	Longtitude	Growth region
DE4	06.08.19	900	47,57589	11,03112	Mittlere Bayerische Kalkalpen
DE5	06.08.19	850	47,57622	11,0622	Mittlere Bayerische Kalkalpen
DE6	07.08.19	1100	47,6204	11,07008	Oberbayerische Flysch-Voralpen
DE7	07.08.19	1300	47,61973	11,08366	Oberbayerische Flysch-Voralpen

DE8	07.08.19	1100	47,61222	11,08332	Oberbayerische Flysch-Voralpen
DE9	07.08.19	1400	47,61187	11,09544	Oberbayerische Flysch-Voralpen
DE10	06.08.19	1400	47,61339	11,10858	Oberbayerische Flysch-Voralpen
DE11	06.08.19	900	47,60222	11,08333	Oberbayerische Flysch-Voralpen
DE12	07.08.19	1100	47,60208	11,09578	Oberbayerische Flysch-Voralpen
DE13	06.08.19	1200	47,60394	11,11386	Mittlere Bayerische Kalkalpen
DE14	06.08.19	1000	47,59665	11,10209	Mittlere Bayerische Kalkalpen
DE15	05.08.19	1100	47,59778	11,11028	Mittlere Bayerische Kalkalpen
DE16	05.08.19	1300	47,59176	11,10748	Mittlere Bayerische Kalkalpen
DE17	05.08.19	1400	47,58951	11,1011	Mittlere Bayerische Kalkalpen
DE18	05.08.19	1300	47,58843	11,11427	Mittlere Bayerische Kalkalpen
DE19	05.08.19	1100	47,57555	11,09689	Mittlere Bayerische Kalkalpen
DE20	05.08.19	1000	47,57419	11,10637	Mittlere Bayerische Kalkalpen

Table 16. PAR3 Oberammergau/Ettal vegetation types and forest parameters of forest data records used for forest growth simulations under climate change scenarios.

ID	Vegetation type	Main tree species[1]	Mean dbh[2] (cm)	Mean height (m)	Stems/ha
DE4	tiefmontan bis subalpiner Bergmischwald und Fichtenwald	FXEX, FASY	38	23	436
DE5	see above	FASY, PCAB	46	30	293
DE6	see above	PCAB	53	33	167
DE7	see above	PCAB	52	31	288
DE8	see above	PCAB	47	28	545
DE9	see above	PCAB	54	30	452
DE10	see above	PCAB	25	17	1590
DE11	see above	PCAB	33	26	777
DE12	see above	PCAB	28	23	1333
DE13	see above	PCAB	56	33	235
DE14	see above	PCAB	45	34	222
DE15	see above	PCAB	30	25	977
DE16	see above	PCAB	57	29	207
DE17	see above	PCAB	50	21	240
DE18	see above	PCAB	49	28	469
DE19	see above	FASY, ABAL	27	14	385
DE20	see above	PCAB	42	30	276

[1]Species code following EN 13556 (https://de.wikipedia.org/wiki/DIN_EN_13556)

[2]dbh = diameter at breast height

Table 17. PAR3 Oberammergau/Ettal site parameters of forest data records used for forest growth simulations under climate change scenarios.

ID	Slope (°)	Exposition (°)	Relief[1]	Soil type	Water balance[1]	Soil depth[1]
DE4	34	170	3	Pararenzina	2	1
DE5	16	170	3	Braunerde	1	2
DE6	12	260	2	Pseudogley-Braunerde	1	2
DE7	17	160	2	Pseudogley-Braunerde	2	2
DE8	27	260	2	Pseudogley-Braunerde	2	2
DE9	35	260	2	Braunerde	1	1
DE10	27	120	2	Braunerde	1	1
DE11	25	230	3	Pseudogley-Braunerde	1	2
DE12	23	230	2	Pseudogley-Braunerde	1	2
DE13	30	230	2	Pseudogley-Braunerde	2	2
DE14	22	20	2	Rendzina	1	1
DE15	24	300	2	Rendzina	1	1
DE16	10	300	2	Rendzina	1	2
DE17	27	250	2	Rendzina	2	1

DE18	33	20	2	Rendzina	1	2
DE19	27	115	2	Podsol-Braunerde	3	2
DE20	28	250	3	Braunerde	1	2

[1]See Appendix A for definition of classes

3.5 PAR4 Parc des Baronnies; France

Since CALDIS was originally developed for the Austrian National Forest Inventory (ANFI) data and parameterized for growth regions specific to Austria, simulations could not be performed for PAR4 Parc des Baronnies in France; growth conditions in this region of the AS differ significantly from growth conditions found in Austria.

3.6 PAR5 Southern Wipptal, Italy

The required data records for PAR5 were collected and compiled in August 2019 using angle-count sampling (Bitterlich, 1948). Gathered basic information (Table 18), forest parameters (Table 19), and site characteristics (Table 20) are summarized below.

Table 18. PAR5 Southern Wipptal basic information and sampling locations of forest data records used for forest growth simulations under climate change scenarios.

ID	Sampling date (DD.MM.YY)	Elevation (m)	Latitude	Longtitude	Growth region
IT_5A	19.08.19	1483	47,003166	11,509714	Randliche Innenalpen
IT_5B	19.08.19	1463	46,958103	11,465544	Randliche Innenalpen
IT_5C	19.08.20	1487	46,96203	11,335393	Zentrale Innenalpen
IT_5D	19.08.19	1538	46,942268	11,393295	Zentrale Innenalpen
IT_5E	19.08.20	1118	46,930862	11,451287	Randliche Innenalpen
IT_5F	19.08.19	1348	46,946765	11,388278	Südliche Zwischenalpen
IT_5G	08.06.19	1250	46,93584	11,39826	Randliche Innenalpen
IT_5H	19.08.20	1557	46,91675	11,528264	Randliche Innenalpen
IT_5I	19.08.20	1473	46,951259	11,554769	Randliche Innenalpen
IT_5J	19.08.20	1821	46,984764	11,647815	Südliche Zwischenalpen

Table 19. PAR5 Southern Wipptal vegetation types and forest parameters of forest data records used for forest growth simulations under climate change scenarios.

ID	Vegetation type	Main tree species[1]	Mean dbh[2] (cm)	Mean height (m)	Stems/ha
IT_5A		PCAB	31	23	
IT_5B		PCAB	31	19	
IT_5C		PCAB	54	41	
IT_5D		PCAB	34	25	
IT_5E		PCAB	35	26	
IT_5F		PCAB	60	34	
IT_5G		PCAB, LADC	45	27	
IT_5H		LADC, PCAB	29	27	
IT_5I		PCAB, LADC	45	27	
IT_5J		PCAB, LADC	50	26	

[1]Species code following EN 13556 (https://de.wikipedia.org/wiki/DIN_EN_13556)
[2]dbh = diameter at breast height

Table 20. PAR5 Southern Wipptal site parameters of forest data records used for forest growth simulations under climate change scenarios.

ID	Slope (°)	Exposition (°)	Relief[1]	Soil type	Water balance[1]	Soil depth[1]
IT_5A	60	45	2	hoher Skelettgehalt, schluffig-lehmig	3	2
IT_5B	65	260	2	Kalk Braunlehm, Kalkmoder	3	2
IT_5C	55	80	2	podsolierte oder basenarme Braunerden	2	1
IT_5D	70	65	2	podsolierte oder basenarme Braunerden	2	1
IT_5E	68	220	2	Rendzina-Pararendzina, Kalk-Braunerde, hoher Skelettgehalt	1	1
IT_5F	64	285	2	podsolierte oder basenarme Braunerden	2	1
IT_5G	60	20	2	Braunlehm-Rendzina, Pararemdzina	2	1
IT_5H	50	300	2	frische Kalkbraunerde, verbraunte Pararendzina	3	2
IT_5I	45	55	2	Braunlehm-Rendzina, Pararemdzina	2	1
IT_5J	55	135	2	Semipodsole oder podsolige, basenarme Braunerden	1	1

[1]See Appendix A for definition of classes

3.7 PAR6 Vals/Gries am Brenner, Austria

For PAR6 two different data sampling strategies were developed:

1) Seven sampling locations were chosen based on their location in important direct object protection forests (data records with IDs AT200-AT206; Figure 4). These sampling points were surveyed in August and September 2019 by applying a fixed-radius sampling design with radii (dependent on the development stage of the forest) of r = 5.64 m (dbh 105-204 mm), r = 12.62 m (dbh 205-504 mm), or r = 17.84 m (dbh > 504 mm). Every tree that was located within a circle with the respective radius was measured and recorded. Data record for these sampling locations are summarized in Table 21, Table 22, and Table 23.

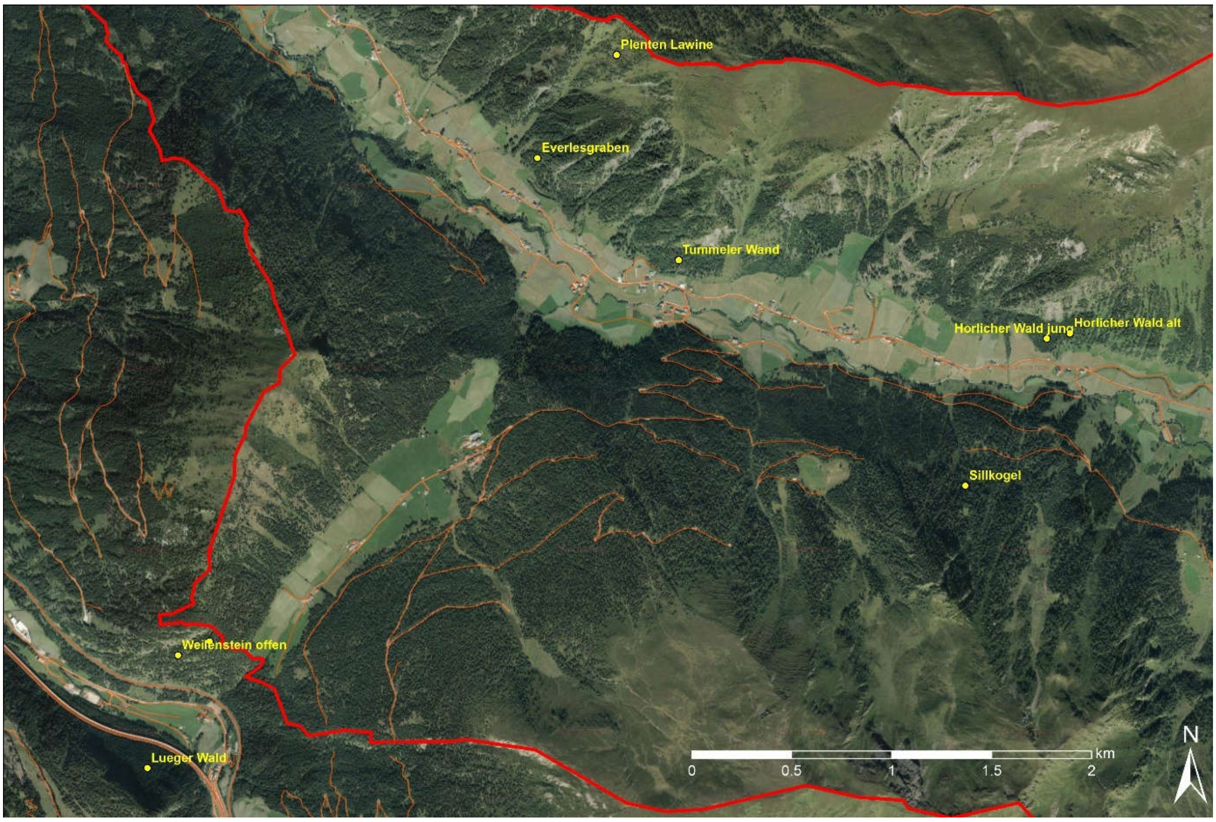

Figure 4. Sampling locations of the seven data records (ID AT200-2006; see Table 21) in PAR6 Vals/Gries am Brenner, Austria (yellow), which included basic, forest and site parameters required for forest growth simulations under climate change scenarios; planned sampling point "Lueger Wald" was not surveyed due to dangerous site conditions; Vals municipality boundary in red.

2) Additional 127 sampling points were arranged in a regular 100-m grid over an area of approximately 137 ha (Figure 5), of which 108 were located in forest (see Appendix B). This area was of particular interest since it is heavily damaged by game browsing. These sampling points were surveyed between August 22 and September 5, 2019 with the "6-Baum-Stichprobe" method (6-tree sample; Prodan, 1962). That is, from each grid point i the 6th closest tree (T_6) is determined and the distance to that tree is measured. This tree as well as the other 5 trees (T_{5-1}), which are located within the distance between i and T_6 are measured. Each sampling plot area can then be calculated from the distance between i and T_6. Summaries of basic information (Appendix B), forest and vegetation parameters (Appendix C) and site characteristics (Appendix D) can be found in the Appendices.

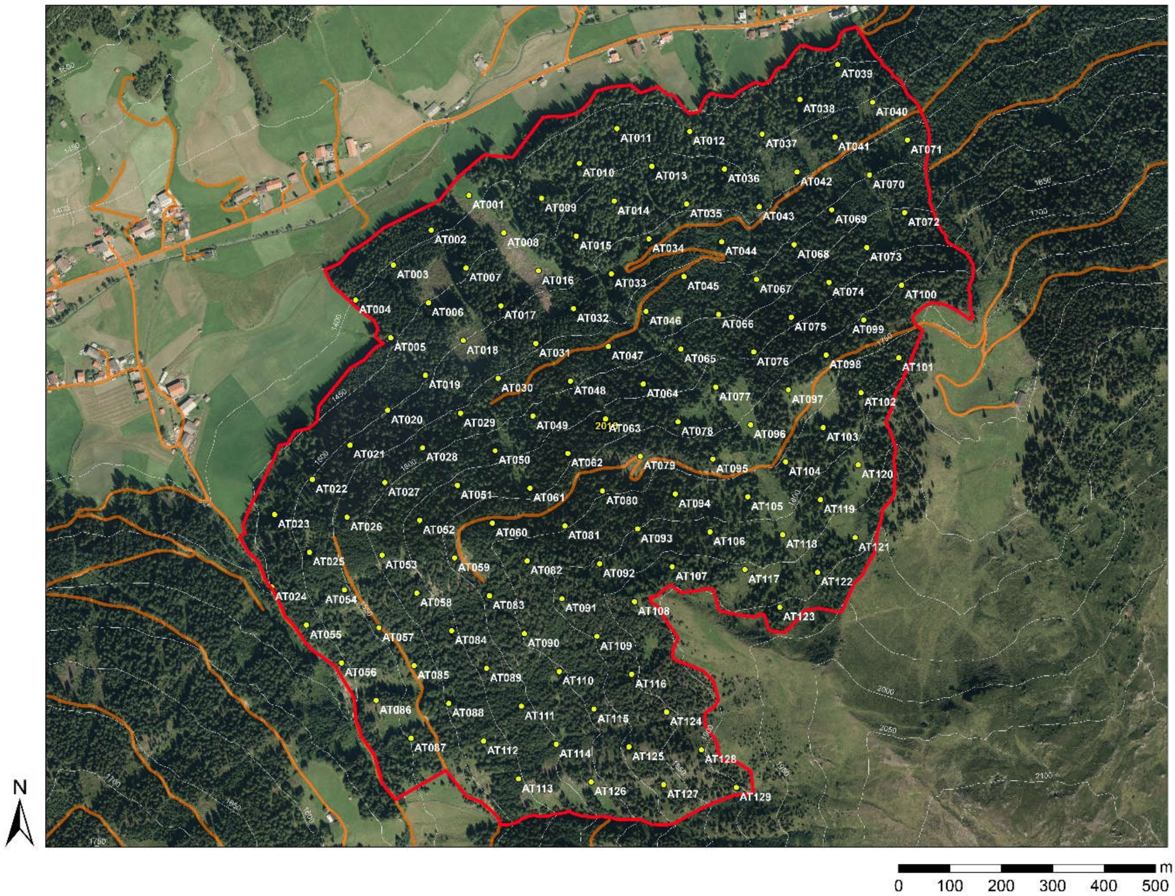

Figure 5. Locations of sampling points for data records required for forest growth simulations under climate change scenarios that were arranged in a regular 100-m grid in an object protection forest in PAR6 Vals/Gries am Brenner, Austria (yellow). Sampling area boundary in red.

Table 21. PAR6 Vals/Gries am Brenner basic information and sampling locations of forest data records used for forest growth simulations under climate change scenarios.

ID	Sampling date (DD.MM.YY)	Elevation (m)	Latitude	Longtitude	Growth region
AT200	31.08.19	1367	47,05147	11,52343	Subkontinentale Innenalpen - Westteil
AT201	31.08.19	1331	47,0428	11,55643	Subkontinentale Innenalpen - Westteil
AT202	31.08.19	1413	47,04353	11,55785	Subkontinentale Innenalpen - Westteil
AT203	01.09.19	1609	47,0364	11,55153	Subkontinentale Innenalpen - Westteil
AT204	01.09.19	1309	47,04649	11,53317	Subkontinentale Innenalpen - Westteil
AT205	03.09.19	1627	47,02988	11,50232	Subkontinentale Innenalpen - Westteil
AT206	03.09.19	1902	47,05609	11,52995	Subkontinentale Innenalpen - Westteil

Table 22. PAR6 Vals/Gries am Brenner vegetation types and forest parameters of forest data records used for forest growth simulations under climate change scenarios.

ID	Vegetation type	Main tree species[1]	Mean dbh[2] (cm)	Mean height (m)	Stems/ha
AT200	Montaner warmer Karbonat-Fichtenwald	LADC	38	22	305

AT201	Frischer Karbonat-Fichten-Tannenwald	PCAB	13	12	3619
AT202	Warmer basischer (Lärchen-)Fichtenwald	PCAB	20	15	900
AT203	Subalpiner basischer Lärchen-Fichtenwald	PCAB	19	13	568
AT204	Montaner warmer Karbonat-Fichtenwald	LADC	59	30	196
AT205	Montaner warmer Karbonat-Fichtenwald	PCAB, LADC, PNNN	27	16	652
AT206	Subalpiner trockener Karbonat-(Lärchen-)Fichtenwald	LADC, PCAB	15	8	618

[1]Species code following EN 13556 (https://de.wikipedia.org/wiki/DIN_EN_13556)

[2]dbh = diameter at breast height

Table 23. PAR6 Vals/Gries am Brenner site parameters of forest data records used for forest growth simulations under climate change scenarios.

ID	Slope (°)	Exposition (°)	Relief[1]	Soil type	Water balance[1]	Soil depth[1]
AT200	38	230	2	Hangschutt silikatisch-karbonatreich	2	2
AT201	31	196	3	Hangschutt silikatisch-karbonatreich	3	1
AT202	39	206	2	Silikatgesteine kalkarm	2	1
AT203	36	8	2	Hangschutt silikatisch-karbonatreich	3	2
AT204	40	200	3	Kies/Schotter silikatisch-karbonatreich	1	2
AT205	40	201	2	Silikatgesteine kalkarm	2	1
AT206	36	255	1	Silikatgesteine kalkreich	2	2

[1]See Appendix A for definition of classes

4 Summary and conclusions

The present report summarizes the spatial and non-spatial forest data that were collected and provided by the institutions responsible for each GR4A PAR, and further employed in WPs 1 and 3 as input data for modeling forest's protective functions and effects, and for simulating the impact of CC scenarios on the growth of protection forests. Similar to collecting and compiling data on existing elements at risk and protection forest measures (see D.T2.4.2), it was found that this is not an easy task since especially spatial forest data:

- comes in different qualities and/or information depths, and
- in varying formats and resolutions,
- is not always publicly available, and
- collected, documented, updated and provided by several authorities and/or institutions, which differs from country to country,
- and even knowledge of such data and/or access to the authorities responsible for the data is not always available,

which can result in heterogeneous model input data and make an objective comparison of modeling results challenging.

The same is true for forest input data to model impacts of CC on the development of protection forests, which was mainly collected in field surveys due to:

- the Austrian specific input data requirements for CALDIS, which was originally developed for ANFI data,
- differences in forest mensuration techniques between the countries,
- not clear enough instructions, and/or
- the lack of time to train the personnel that collected the data.

However, it was much easier to transfer the data submitted for each PAR into the format needed for CALDIS simulations compared to pre-processing spatial forest data for Flow-py.

Therefore, a harmonization and/or even standardization over the AS of forest inventory methods and data management systems to gather and access spatial and non-spatial forest data would greatly increase the significance and applicability of decision supporting methods and tools that are being in GR4A, but also in many other national and international research projects.

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Appendix A: Instructions for collecting forest and site parameters

Please provide data records for forest and site parameters for no more than 15-20 areas of interest. We will focus on maximum three main forest types in each PAR such as subalpine spruce, spruce-fir and/or spruce-fir-beech forests (or other main forest types in your PAR), and on forests with a protective function or with functions that are particularly of interest in your PAR.

Goal: Since in GreenRisk4ALPs, we decided to not use the forest development projections (future climate change driven forest scenarios) for detailed hazard modeling but rather as basis for discussions, we will focus those projections on protection forests with a direct object protection function including "hot-spot/cold-spot" areas (or on forests with other functions that are particularly of interest in your PAR).

In General: When designing your field work, keep in mind that the spatial arrangement and resolution of your sampling points to gather the data required for projecting the forest's development under climate change with CALDIS depends on the goal and further use of the results. In general, forest development projections are made for the observation unit; the **observation unit can be a point** (e.g. collected by sample plots and/or angle count samples) **or a stand** (e.g. averaged for stand-scale from point observations or estimated). Once you've decided, what areas you are considering as important/of interest and would like to have projections for, please provide forest and site parameters that represent the present forest (e.g. at two to three different elevations, if the forest stand is covering a slope).

Important: All parameters can also be estimated from nearby forest inventory points or from other data sources (but: as more accurate the input data, as more accurate the results); however, please make sure that the provided data represents the forest of interest and not only one inventory point. For example, if the area/stand of interest is very inhomogeneous in space (e.g. some parts are very dense, others are sparsely covered by trees), it should be split up in more or less homogenous sub-stands as representative mean values are typically not able to describe the heterogeneity in space. However, multi-storied stands do not need to be split up in separate sub-stands (i.e. parameters for each layer need to be submitted with the same stand and sampling point ID. An example is provided in the Excel-template.)

When you submit your data, please also provide a documentation of how this data was collected/gathered, e.g. via angle count samples, other sampling plot methods, estimates/model output based on forest inventory points, or other data sources since this will be part of the deliverable D.T1.1.3 "Report on 'New assessment methods for protection forests in the AS".

An Excel-file is provided to fill in your data.

Basic information:

- ID (each record of forest and site parameters should have one unique ID that links forest, site and other parameters - starting with the two character ISO 3166 country code [https://en.wikipedia.org/wiki/List_of_ISO_3166_country_codes], and followed by, e.g., a two digit stand ID, and, if sample plot data is provided, a three digit sample ID, e.g. AT01001, AT01002, AT02001, etc.)
- sampling date, if possible
- stand size (ha) (if the record is representing a forest stand)

For each ID/record, the following **forest parameters** need to be provided:

- Tree species (Species code following EN 13556 [https://de.wikipedia.org/wiki/DIN_EN_13556])
- Diameter at breast height (dbh) (cm)
- Tree height (m)
- Crown height (height up to the beginning of the living crown) (m)
- Number of stems per ha

If you submit data collected by sample plots/angle count samples, forest parameters need to be provided per tree [single parameters can also be estimated]. If you submit stand-based estimates, forest parameters need to be submitted per unique type. For example, for a two-layer single species stand you have to submit at least two lines of data, one for each layer. An example is provided in the Excel-template.

The **site parameters** are:

- Slope angle (°)
- Exposition (°)
- Relief: position of the stand on a slope/in the landscape in 8 classes:

1 upper slope/convex slope
2 middle slope
3 lower slope/concave slope
4 trench
5 valley bottom
6 flat
7 depression
8 stream

- Soil type (based on expert opinion/according to the Austrian National Forest Inventory ANFI) → please provide any information on soil type that we can match it to the ANFI specifications
- Vegetation type (based on expert opinion/according to the ANFI) → please provide any information on vegetation type that we can match it to the ANFI specifications
- Elevation (m)
- Position (Lat, Lon)
- Water balance/hydrological regime (estimated in 5 classes):

1 dry
2 moderately fresh
3 fresh
4 very fresh
5 wet

- Soil depth (2 classes; in most cases >30 cm):

1, 0-30 cm
2, >30 cm

- Growing region (based on expert opinion/according to the ANFI) → please provide any information on yield or site class that we can match it to the ANFI specifications

Optional/additional data:

- Site index per tree species (dominant tree height at age 100)

Forest management/harvesting scenarios:
Information on planned/future forest management (thinning, harvesting) are necessary for predictions > 20 years into the future. These can be derived from past management strategies in the form of targeted tree height, targeted dbh, targeted stand density for harvesting decisions, mean harvest volume in percent, etc. The goal is to project the probability that a tree gets harvested based on the available input information.

Appendix B: Basic information of forest data grid-sampling points in PAR6 Vals/Gries am Brenner, Austria

ID	Sampling date (MM/DD/YYYY)	Elevation (m)	Latitude	Longtitude	Growth region
AT002	8/22/2019	1394	47.0177	11.43313	Subkontinentale Innenalpen - Westteil
AT003	8/22/2019	1404	47.01709	11.43216	Subkontinentale Innenalpen - Westteil
AT004	8/22/2019	1402	47.01649	11.43118	Subkontinentale Innenalpen - Westteil
AT005	8/22/2019	1440	47.01582	11.43206	Subkontinentale Innenalpen - Westteil
AT007	8/22/2019	1444	47.01703	11.43401	Subkontinentale Innenalpen - Westteil
AT009	8/22/2019	1432	47.01823	11.43597	Subkontinentale Innenalpen - Westteil
AT010	8/22/2019	1431	47.01883	11.43695	Subkontinentale Innenalpen - Westteil
AT011	8/22/2019	1417	47.01943	11.43793	Subkontinentale Innenalpen - Westteil
AT012	8/22/2019	1423	47.01936	11.43978	Subkontinentale Innenalpen - Westteil
AT013	8/22/2019	1459	47.01876	11.43881	Subkontinentale Innenalpen - Westteil
AT014	8/22/2019	1468	47.01816	11.43783	Subkontinentale Innenalpen - Westteil
AT015	8/23/2019	1468	47.01756	11.43685	Subkontinentale Innenalpen - Westteil
AT017	8/23/2019	1491	47.01636	11.43489	Subkontinentale Innenalpen - Westteil
AT019	8/23/2019	1491	47.01516	11.43293	Subkontinentale Innenalpen - Westteil
AT020	8/23/2019	1500	47.01455	11.43196	Subkontinentale Innenalpen - Westteil
AT021	8/23/2019	1509	47.01395	11.43098	Subkontinentale Innenalpen - Westteil
AT022	8/23/2019	1505	47.01335	11.43	Subkontinentale Innenalpen - Westteil
AT023	8/23/2019	1476	47.01275	11.42902	Subkontinentale Innenalpen - Westteil
AT024	8/23/2019	1450	47.01148	11.42892	Subkontinentale Innenalpen - Westteil
AT025	8/24/2019	1508	47.01208	11.4299	Subkontinentale Innenalpen - Westteil
AT026	8/24/2019	1571	47.01268	11.43088	Subkontinentale Innenalpen - Westteil
AT027	8/24/2019	1589	47.01328	11.43186	Subkontinentale Innenalpen - Westteil
AT028	8/24/2019	1572	47.01389	11.43284	Subkontinentale Innenalpen - Westteil
AT029	8/24/2019	1560	47.01449	11.43381	Subkontinentale Innenalpen - Westteil
AT030	8/24/2019	1554	47.01509	11.43479	Subkontinentale Innenalpen - Westteil
AT031	8/24/2019	1544	47.01569	11.43577	Subkontinentale Innenalpen - Westteil
AT032	8/24/2019	1517	47.01629	11.43675	Subkontinentale Innenalpen - Westteil
AT033	8/24/2019	1513	47.01689	11.43773	Subkontinentale Innenalpen - Westteil
AT034	8/24/2019	1509	47.01749	11.43871	Subkontinentale Innenalpen - Westteil
AT035	8/24/2019	1495	47.01809	11.43968	Subkontinentale Innenalpen - Westteil
AT037	8/25/2019	1441	47.01929	11.44164	Subkontinentale Innenalpen - Westteil
AT038	8/25/2019	1428	47.01989	11.44262	Subkontinentale Innenalpen - Westteil
AT039	8/25/2019	1405	47.0205	11.4436	Subkontinentale Innenalpen - Westteil
AT041	8/25/2019	1475	47.01923	11.4435	Subkontinentale Innenalpen - Westteil
AT043	8/25/2019	1494	47.01802	11.44154	Subkontinentale Innenalpen - Westteil
AT044	8/25/2019	1525	47.01742	11.44056	Subkontinentale Innenalpen - Westteil
AT045	8/25/2019	1558	47.01682	11.43958	Subkontinentale Innenalpen - Westteil
AT046	8/26/2019	1572	47.01622	11.43861	Subkontinentale Innenalpen - Westteil
AT047	8/26/2019	1571	47.01562	11.43763	Subkontinentale Innenalpen - Westteil
AT048	8/26/2019	1589	47.01502	11.43665	Subkontinentale Innenalpen - Westteil
AT049	8/26/2019	1613	47.01442	11.43567	Subkontinentale Innenalpen - Westteil
AT050	8/26/2019	1630	47.01382	11.43469	Subkontinentale Innenalpen - Westteil
AT051	8/27/2019	1661	47.01322	11.43371	Subkontinentale Innenalpen - Westteil
AT053	8/27/2019	1613	47.01201	11.43176	Subkontinentale Innenalpen - Westteil
AT054	8/27/2019	1543	47.01141	11.43078	Subkontinentale Innenalpen - Westteil
AT055	8/27/2019	1483	47.01081	11.4298	Subkontinentale Innenalpen - Westteil
AT056	8/27/2019	1497	47.01014	11.43068	Subkontinentale Innenalpen - Westteil
AT057	8/27/2019	1558	47.01074	11.43166	Subkontinentale Innenalpen - Westteil
AT058	8/27/2019	1626	47.01134	11.43264	Subkontinentale Innenalpen - Westteil
AT059	8/27/2019	1710	47.01195	11.43361	Subkontinentale Innenalpen - Westteil
AT060	8/27/2019	1727	47.01255	11.43459	Subkontinentale Innenalpen - Westteil
AT061	8/27/2019	1682	47.01315	11.43557	Subkontinentale Innenalpen - Westteil
AT062	8/27/2019	1692	47.01375	11.43655	Subkontinentale Innenalpen - Westteil
AT063	8/27/2019	1665	47.01435	11.43753	Subkontinentale Innenalpen - Westteil
AT064	8/28/2019	1629	47.01495	11.43851	Subkontinentale Innenalpen - Westteil
AT065	8/28/2019	1616	47.01555	11.43948	Subkontinentale Innenalpen - Westteil

AT066	8/28/2019	1594	47.01615	11.44046	Subkontinentale Innenalpen - Westteil
AT068	8/28/2019	1562	47.01735	11.44242	Subkontinentale Innenalpen - Westteil
AT069	8/28/2019	1557	47.01796	11.4434	Subkontinentale Innenalpen - Westteil
AT070	8/28/2019	1552	47.01856	11.44438	Subkontinentale Innenalpen - Westteil
AT072	8/28/2019	1608	47.01789	11.44526	Subkontinentale Innenalpen - Westteil
AT073	8/29/2019	1633	47.01729	11.44428	Subkontinentale Innenalpen - Westteil
AT074	8/29/2019	1631	47.01669	11.4433	Subkontinentale Innenalpen - Westteil
AT075	8/29/2019	1635	47.01608	11.44232	Subkontinentale Innenalpen - Westteil
AT076	8/29/2019	1646	47.01548	11.44134	Subkontinentale Innenalpen - Westteil
AT078	8/29/2019	1682	47.01428	11.43938	Subkontinentale Innenalpen - Westteil
AT080	8/29/2019	1748	47.01308	11.43743	Subkontinentale Innenalpen - Westteil
AT081	8/29/2019	1747	47.01248	11.43645	Subkontinentale Innenalpen - Westteil
AT082	8/29/2019	1775	47.01188	11.43547	Subkontinentale Innenalpen - Westteil
AT083	8/30/2019	1711	47.01128	11.43449	Subkontinentale Innenalpen - Westteil
AT084	8/30/2019	1641	47.01068	11.43351	Subkontinentale Innenalpen - Westteil
AT085	8/30/2019	1574	47.01007	11.43254	Subkontinentale Innenalpen - Westteil
AT086	8/30/2019	1522	47.00947	11.43156	Subkontinentale Innenalpen - Westteil
AT087	8/30/2019	1551	47.0088	11.43244	Subkontinentale Innenalpen - Westteil
AT088	8/30/2019	1607	47.00941	11.43342	Subkontinentale Innenalpen - Westteil
AT089	8/30/2019	1665	47.01001	11.43439	Subkontinentale Innenalpen - Westteil
AT090	8/30/2019	1751	47.01061	11.43537	Subkontinentale Innenalpen - Westteil
AT091	8/30/2019	1809	47.01121	11.43635	Subkontinentale Innenalpen - Westteil
AT092	8/30/2019	1805	47.01181	11.43733	Subkontinentale Innenalpen - Westteil
AT093	8/30/2019	1798	47.01241	11.43831	Subkontinentale Innenalpen - Westteil
AT094	9/3/2019	1771	47.01301	11.43929	Subkontinentale Innenalpen - Westteil
AT095	9/3/2019	1733	47.01361	11.44026	Subkontinentale Innenalpen - Westteil
AT097	9/3/2019	1723	47.01481	11.44222	Subkontinentale Innenalpen - Westteil
AT098	9/3/2019	1720	47.01542	11.4432	Subkontinentale Innenalpen - Westteil
AT099	9/3/2019	1707	47.01602	11.44418	Subkontinentale Innenalpen - Westteil
AT100	9/3/2019	1706	47.01662	11.44516	Subkontinentale Innenalpen - Westteil
AT101	9/3/2019	1774	47.01535	11.44506	Subkontinentale Innenalpen - Westteil
AT102	9/3/2019	1788	47.01475	11.44408	Subkontinentale Innenalpen - Westteil
AT103	9/3/2019	1762	47.01415	11.4431	Subkontinentale Innenalpen - Westteil
AT104	9/3/2019	1754	47.01354	11.44212	Subkontinentale Innenalpen - Westteil
AT105	9/3/2019	1775	47.01294	11.44114	Subkontinentale Innenalpen - Westteil
AT106	9/4/2019	1823	47.01234	11.44016	Subkontinentale Innenalpen - Westteil
AT107	9/4/2019	1878	47.01174	11.43919	Subkontinentale Innenalpen - Westteil
AT108	9/4/2019	1882	47.01114	11.43821	Subkontinentale Innenalpen - Westteil
AT109	9/4/2019	1805	47.01054	11.43723	Subkontinentale Innenalpen - Westteil
AT110	9/4/2019	1746	47.00994	11.43625	Subkontinentale Innenalpen - Westteil
AT111	9/4/2019	1689	47.00934	11.43527	Subkontinentale Innenalpen - Westteil
AT112	9/4/2019	1622	47.00874	11.43429	Subkontinentale Innenalpen - Westteil
AT113	9/4/2019	1642	47.00807	11.43517	Subkontinentale Innenalpen - Westteil
AT114	9/4/2019	1699	47.00867	11.43615	Subkontinentale Innenalpen - Westteil
AT115	9/4/2019	1770	47.00927	11.43713	Subkontinentale Innenalpen - Westteil
AT116	9/5/2019	1837	47.00987	11.43811	Subkontinentale Innenalpen - Westteil
AT119	9/5/2019	1828	47.01287	11.443	Subkontinentale Innenalpen - Westteil
AT122	9/5/2019	1883	47.0116	11.4429	Subkontinentale Innenalpen - Westteil
AT123	9/5/2019	1912	47.011	11.44192	Subkontinentale Innenalpen - Westteil
AT124	9/5/2019	1842	47.0092	11.43899	Subkontinentale Innenalpen - Westteil
AT125	9/5/2019	1815	47.0086	11.43801	Subkontinentale Innenalpen - Westteil
AT127	9/5/2019	1819	47.00793	11.43889	Subkontinentale Innenalpen - Westteil

Appendix C: Forest parameters of forest data grid-sampling points in PAR6 Vals/Gries am Brenner, Austria

ID	Vegetation type	Main tree species[1]	Mean dbh[2] (cm)	Mean height (m)	Stems/ha
AT002	Montaner frischer basischer Fichtenwald	PCAB	26	15	189
AT003	Montaner frischer basischer Fichtenwald	PCAB	24	14	209
AT004	Montaner frischer basischer Fichtenwald	PCAB	29	16	127
AT005	Montaner frischer basischer Fichtenwald	PCAB	11	7	292
AT007	Montaner armer Silikat-(Lärchen-)Fichtenwald	PCAB	43	22	86
AT009	Montaner armer Silikat-(Lärchen-)Fichtenwald	LADC	36	18	65
AT010	Montaner frischer basischer Fichtenwald	LADC	42	22	127
AT011	Montaner frischer basischer Fichtenwald	PCAB	17	13	199
AT012	Montaner frischer basischer Fichtenwald	PCAB	21	15	722
AT013	Montaner armer Silikat-(Lärchen-)Fichtenwald	PCAB	30	18	3183
AT014	Montaner armer Silikat-(Lärchen-)Fichtenwald	PCAB	27	16	127
AT015	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	23	11	796
AT017	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	43	21	127
AT019	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	26	15	509
AT020	Subalpiner kühler Silikat-Steilhang-(Grünerlen-Lärchen-)Fichtenwald	PCAB	24	16	354
AT021	Subalpiner kühler Silikat-Steilhang-(Grünerlen-Lärchen-)Fichtenwald	PCAB	27	18	49
AT022	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	21	15	982
AT023	Montaner frischer basischer Fichtenwald	PCAB	21	15	246
AT024	Reicher Silikat-Fichten-Tannenwald	PCAB	14	14	509
AT025	Warmer basischer (Lärchen-)Fichtenwald	PCAB	23	14	354
AT026	Montaner trockener Silikat-(Kiefern-)Fichtenwald	PCAB	9	9	138
AT027	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	34	19	275
AT028	Subalpiner kühler Silikat-Steilhang-(Grünerlen-Lärchen-)Fichtenwald	PCAB	29	17	311
AT029	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	40	21	38
AT030	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	25	17	180
AT031	Montaner armer Silikat-(Lärchen-)Fichtenwald	PCAB	68	26	38

AT032	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	19	16	3183
AT033	Montaner armer Silikat-(Lärchen-)Fichtenwald	PCAB	18	14	3930
AT034	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	12	7	1415
AT035	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	32	21	75
AT037	Montaner frischer basischer Fichtenwald	PCAB	18	14	722
AT038	Montaner frischer basischer Fichtenwald	PCAB	12	9	2210
AT039	Montaner frischer basischer Fichtenwald	PCAB	42	22	331
AT041	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	33	23	722
AT043	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	20	14	509
AT044	Montaner armer Silikat-(Lärchen-)Fichtenwald	PCAB	12	9	3183
AT045	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	12	7	882
AT046	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	33	24	982
AT047	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	19	13	796
AT048	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	38	24	354
AT049	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	17	12	1101
AT050	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	33	21	2210
AT051	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	PCAB	30	19	260
AT053	Montaner warmer Silikat-(Lärchen-)Fichtenwald	PCAB	19	12	1243
AT054	Warmer basischer (Lärchen-)Fichtenwald	PCAB	11	7	1101
AT055	Montaner warmer Silikat-(Lärchen-)Fichtenwald	PCAB	32	17	406
AT056	Montaner frischer basischer Fichtenwald	PCAB	29	13	354
AT057	Montaner warmer Karbonat-Fichtenwald	PCAB	35	19	86
AT058	Montaner warmer Silikat-(Lärchen-)Fichtenwald	PCAB	30	18	553
AT059	Montaner warmer Silikat-(Lärchen-)Fichtenwald	PCAB	16	10	982
AT060	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	PCAB	21	15	354
AT061	Subalpiner Auflagehumus-Karbonat-Lärchen-Fichtenwald	PCAB	16	11	1101
AT062	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	PCAB	23	17	311
AT063	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	PCAB	35	20	122
AT064	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	28	18	882
AT065	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	25	12	437
AT066	Montaner armer Silikat-(Lärchen-)Fichtenwald	PCAB	29	19	331

AT068	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	34	21	796
AT069	Montaner frischer basischer Fichtenwald	PCAB	12	11	2631
AT070	Montaner armer Karbonat-Lärchen-Fichtenwald	PCAB	14	10	311
AT072	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	31	18	127
AT073	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	19	13	882
AT074	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	29	17	354
AT075	Subalpiner kühler Silikat-Steilhang-(Grünerlen-Lärchen-)Fichtenwald	PCAB	35	20	65
AT076	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	32	19	49
AT078	Lawinar-Silikat-(Grünerlen-)Lärchen-Fichtenwald	PCAB	30	18	275
AT080	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	PCAB	28	9	354
AT081	Subalpiner Auflagehumus-Karbonat-Lärchen-Fichtenwald	PCAB	13	9	982
AT082	Subalpiner warmer Silikat-Lärchen-Fichtenwald	PCAB	32	19	354
AT083	Subalpiner trockener Karbonat-(Lärchen-)Fichtenwald	PCAB	14	9	3183
AT084	Montaner warmer Silikat-(Lärchen-)Fichtenwald	PCAB	19	12	796
AT085	Montaner frischer basischer Fichtenwald	PCAB	17	12	1415
AT086	Montaner frischer basischer Fichtenwald	PCAB	34	14	164
AT087	Montaner warmer Silikat-(Lärchen-)Fichtenwald	PCAB	16	12	722
AT088	Montaner trockener Silikat-(Kiefern-)Fichtenwald	PCAB	29	19	199
AT089	Montaner frischer Silikat-(Lärchen-)Fichtenwald	PCAB	26	17	199
AT090	Subalpiner trockener Silikat-Lärchen-Fichtenwald	PCAB	29	16	658
AT091	Subalpiner warmer Silikat-Lärchen-Fichtenwald	PCAB	20	13	722
AT092	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	PCAB	15	11	65
AT093	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	PCAB	22	14	882
AT094	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	PCAB	20	14	982
AT095	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	PCAB	20	12	509
AT097		PCAB	31	18	157
AT098	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	PCAB	33	19	57
AT099	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	PCAB	35	20	260
AT100	Subalpiner kühler Silikat-Steilhang-(Grünerlen-Lärchen-)Fichtenwald	PCAB	33	14	199
AT101	Subalpiner kühler Silikat-Steilhang-(Grünerlen-Lärchen-)Fichtenwald	PCAB	28	19	602

AT102	Lawinar-Silikat-(Grünerlen-)Lärchen-Fichtenwald	PCAB	30	20	982
AT103	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	PCAB	36	20	796
AT104	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	PCAB	20	16	1415
AT105	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	PCAB	30	20	437
AT106	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	PCAB	41	20	86
AT107	Armer Silikat-Lärchen-Zirbenwald	PCAB	31	19	311
AT108	Subalpiner trockener Silikat-Lärchen-Fichtenwald	PCAB	18	14	246
AT109	Subalpiner warmer Silikat-Lärchen-Fichtenwald	PCAB	14	10	354
AT110	Subalpiner warmer Silikat-Lärchen-Fichtenwald	PCAB	30	19	127
AT111	Montaner warmer Silikat-(Lärchen-)Fichtenwald	PCAB	34	20	509
AT112	Montaner warmer Silikat-(Lärchen-)Fichtenwald	PCAB	29	19	354
AT113	Montaner warmer Silikat-(Lärchen-)Fichtenwald	PCAB	13	8	3183
AT114	Subalpiner trockener Silikat-Lärchen-Fichtenwald	PCAB	19	13	658
AT115	Subalpiner trockener Silikat-Lärchen-Fichtenwald	PCAB	41	22	180
AT116	Subalpiner trockener Silikat-Lärchen-Fichtenwald	PCAB	39	21	882
AT119	Subalpiner armer Silikat-(Lärchen-)Fichtenwald	PCAB	27	18	378
AT122		PCAB	27	17	180
AT123		PCAB	28	17	354
AT124	Subalpiner trockener Silikat-Lärchen-Fichtenwald	PCAB	24	17	471
AT125	Subalpiner kühler Silikat-Steilhang-(Grünerlen-Lärchen-)Fichtenwald	PCAB	28	17	311
AT127	Latschen, Grünerlen, Laubholz-Buschwälder, Verbuschende Flächen	PCAB	24	13	1101

[1]Species code following EN 13556 (https://de.wikipedia.org/wiki/DIN_EN_13556)

[2]dbh = diameter at breast height

Appendix D: Site characteristics of forest data grid-sampling points in PAR6 Vals/Gries am Brenner, Austria

ID	Slope (°)	Exposition (°)	Relief[1]	Soil type	Water balance[1]	Soil depth[1]
AT002	22	320	3	Kies/Schotter silikatisch-karbonatreich	3	2
AT003	25	322	3	Kies/Schotter silikatisch-karbonatreich	3	2
AT004	22	300	3	Kies/Schotter silikatisch-karbonatreich	3	2
AT005	27	285	3	Moränen silikatisch-karbonatreich	3	2
AT007	33	297	3	Moränen silikatisch-karbonatreich	3	2
AT009	31	280	3	Kies/Schotter silikatisch-intermed.	2	2
AT010	20	324	3	Moränen silikatisch-karbonatreich	2	2
AT011	21	346	3	Moränen silikatisch-karbonatreich	2	2
AT012	29	16	3	Moränen silikatisch-karbonatreich	2	2
AT013	18	333	3	Hangschutt silikatisch-intermed.	2	2
AT014	24	342	3	Hangschutt silikatisch-intermed.	2	2
AT015	23	314	3	Hangschutt silikatisch-intermed.	2	2
AT017	25	340	3	Hangschutt silikatisch-intermed.	2	2
AT019	28	323	7	Hangschutt silikatisch-intermed.	2	2
AT020	39	327	3	Silikatgesteine intermediär	2	2
AT021	42	316	3	Silikatgesteine intermediär	2	2
AT022	36	314	3	Silikatgesteine intermediär	2	2
AT023	34	271	3	Hangschutt silikatisch-karbonatarm	2	2
AT024	23	261	3	Silikatgesteine intermediär	3	2
AT025	36	257	3	Hangschutt silikatisch-karbonatarm	3	2
AT026	41	286	3	Silikatgesteine intermediär	2	2
AT027	37	317	3	Silikatgesteine intermediär	2	1
AT028	41	332	3	Silikatgesteine intermediär	3	1
AT029	40	338	3	Silikatgesteine intermediär	2	2
AT030	31	335	3	Hangschutt silikatisch-intermed.	3	2
AT031	27	323	3	Hangschutt silikatisch-intermed.	3	2
AT032	21	329	3	Hangschutt silikatisch-intermed.	3	2
AT033	37	272	7	Hangschutt silikatisch-intermed.	2	2
AT034	35	343	3	Silikatgesteine intermediär	3	2
AT035	20	354	3	Silikatgesteine intermediär	2	2
AT037	28	321	3	Silikatgesteine intermediär	1	1
AT038	23	336	3	Moränen silikatisch-karbonatreich	2	1
AT039	28	330	3	Moränen silikatisch-karbonatreich	2	1
AT041	27	329	3	Silikatgesteine intermediär	2	1
AT043	41	320	8	Silikatgesteine intermediär	1	2
AT044	32	10	3	Silikatgesteine intermediär	1	2
AT045	24	345	3	Silikatgesteine intermediär	2	2
AT046	29	288	7	Silikatgesteine intermediär	2	2
AT047	29	333	2	Silikatgesteine intermediär	1	1
AT048	28	332	2	Silikatgesteine intermediär	1	1
AT049	41	306	2	Silikatgesteine intermediär	1	2
AT050	39	341	2	Silikatgesteine intermediär	1	2
AT051	36	322	2	Silikatgesteine intermediär	2	2

AT053	39	248	2	Silikatgesteine intermediär	1	1
AT054	31	246	2	Hangschutt silikatisch-karbonatarm	1	1
AT055	33	239	7	Silikatgesteine intermediär	1	2
AT056	32	232	7	Kies/Schotter silikatisch-karbonatreich	2	1
AT057	32	236	2	Hangschutt silikatisch-karbonatarm	1	2
AT058	41	241	2	Silikatgesteine intermediär	3	2
AT059	33	253	2	Silikatgesteine intermediär	1	2
AT060	34	1	2	Silikatgesteine intermediär	3	2
AT061	34	348	2	Dolomite allgemein	3	2
AT062	37	352	7	Silikatgesteine intermediär	2	1
AT063	37	342	2	Silikatgesteine intermediär	2	1
AT064	42	355	2	Silikatgesteine intermediär	1	1
AT065	29	308	2	Silikatgesteine intermediär	2	1
AT066	25	354	2	Silikatgesteine intermediär	2	1
AT068	35	309	7	Dolomite allgemein	3	2
AT069	41	325	2	Dolomite allgemein	2	1
AT070	47	338	2	Dolomite allgemein	1	1
AT072	30	356	2	Silikatgesteine intermediär	2	2
AT073	38	332	2	Silikatgesteine intermediär	3	1
AT074	37	317	7	Silikatgesteine intermediär	2	1
AT075	39	321	2	Silikatgesteine intermediär	3	2
AT076	33	324	7	Silikatgesteine intermediär	1	2
AT078	25	8	2	Silikatgesteine intermediär	2	1
AT080	29	344	2	Silikatgesteine intermediär	2	2
AT081	31	329	2	Dolomite allgemein	2	2
AT082	16	279	2	Silikatgesteine intermediär	2	1
AT083	41	242	2	Dolomite allgemein	2	1
AT084	38	250	2	Silikatgesteine intermediär	3	2
AT085	35	250	2	Kies/Schotter silikatisch-karbonatreich	2	2
AT086	29	290	7	Kies/Schotter silikatisch-karbonatreich	2	2
AT087	29	238	2	Moränen silikatisch-intermed.	2	2
AT088	34	260	2	Silikatgesteine intermediär	2	2
AT089	37	237	2	Silikatgesteine intermediär	2	2
AT090	33	254	2	Silikatgesteine intermediär	2	2
AT091	19	261	1	Silikatgesteine intermediär	2	2
AT092	22	330	7	Silikatgesteine intermediär	3	2
AT093	31	335	1	Silikatgesteine intermediär	3	2
AT094	31	15	1	Silikatgesteine intermediär	4	2
AT095	29	357	1	Hangschutt silikatisch-intermed.	2	2
AT097	29	291	1	Silikatgesteine intermediär	3	2
AT098	38	334	1	Silikatgesteine intermediär	3	2
AT099	38	313	1	Silikatgesteine intermediär	3	2
AT100	36	322	1	Silikatgesteine intermediär	2	2
AT101	35	321	1	Silikatgesteine intermediär	3	2
AT102	32	275	1	Silikatgesteine intermediär	3	2
AT103	30	326	1	Silikatgesteine intermediär	3	2
AT104	31	298	1	Hangschutt silikatisch-intermed.	3	2
AT105	28	331	1	Hangschutt silikatisch-intermed.	2	2
AT106	33	1	1	Silikatgesteine intermediär	3	2
AT107	36	348	1	Silikatgesteine intermediär	2	2
AT108	27	267	1	Silikatgesteine intermediär	3	2
AT109	40	218	1	Silikatgesteine intermediär	5	2
AT110	21	217	1	Silikatgesteine intermediär	2	2
AT111	31	242	1	Silikatgesteine intermediär	3	2
AT112	29	236	1	Silikatgesteine intermediär	3	2
AT113	38	249	1	Silikatgesteine intermediär	3	2
AT114	32	253	1	Silikatgesteine intermediär	2	2

AT115	51	241	1	Silikatgesteine intermediär	2	2
AT116	41	285	1	Silikatgesteine intermediär	5	2
AT119	33	308	1	Silikatgesteine intermediär	2	2
AT122	42	306	1	Silikatgesteine intermediär	2	2
AT123	42	348	1	Silikatgesteine intermediär	4	2
AT124	36	214	4	Silikatgesteine intermediär	2	1
AT125	37	264	1	Silikatgesteine intermediär	2	1
AT127	43	224	1	Silikatgesteine intermediär	3	2

[1]See Appendix A for definition of classes