Chapter

# Geodata Requirements for Mapping Protective Functions and Effects of Forests

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## Abstract

Mapping of protective functions and effects of forests is subject to geodata on 1) natural hazard susceptibilities (hazard potential), 2) assets to be protected (damage potential), and 3) forest conditions, that is, forest use (legal extent) and cover (structure). Objectives in terms of legal definitions of assets and levels of risk acceptance (protection targets) as well as on the necessary and guaranteed reliability of the map products determine the mapping scale and the requirements for the methods and input data to be used. However, applied definitions of protection targets are often missing in the legislative bases and mapping approaches must rather be adapted to the existing geodata, their conceptual data model and quality, than simply using existing methods. Agreeing on the assets to be protected and the quality of their digital representation in terms of spatial resolution, positional accuracy, currentness, topological consistency, and entities is crucial for mapping object protective forests. The reliability of assessing protective effects of forests for large areas based on information acquired with remote sensing techniques depends on the temporal match, spatial and spectral resolutions, and limitations in representing current forest conditions by spectral and elevation data.


**Keywords:** protective (protection) forest, protection targets, protective function, protective effect, natural hazard risk, spatial modeling, mapping, geodata

## 1. Introduction

The protective function of forests defines their role in natural hazard risk mitigation that is required by society. To spatially determine the protective function of forests dependent on a hazard potential and a damage potential is the first level of risk analyses considering the protective capabilities of current or future forests. On this first level, delineating object protective forests (or object protection forests; see chapter [1] of this book) and areas to be potentially afforested, the effect of the current forest is not considered. The term "hazard potential" refers to the onset and propagation probabilities (frequency and magnitude) of natural hazards as well as to their intensity without considering the effects of the current forest cover (and other mitigation measures) on the hazard component of risk. The "damage potential" describes the probability and the relevance of damages to assets like infrastructures due to their exposure and vulnerability — the other two components of risk (see chapter [2] of this book). However, approaches of forest function mapping (e.g., [3–8] and see also book chapters [9–11]) often simplify the hazard intensity as well as the damage potential since they are difficult to assess reliably on a regional scale [5].

The protective effects of forests are their capacity to reduce natural hazard's frequency, magnitude, and/or intensity (see chapters [1, 12] of this book). The next crucial step of an ecosystem-based natural hazard risk management by forest is, therefore, to consider the effects of the existing woody vegetation on hazard frequency, magnitude, and intensity. However, the assessment of the protective effects may be limited to forests with an object protective function to focus on areas at risk, that is, areas with a damage potential.

Modeling and mapping protective functions and effects of forests require geodata on 1) the hazard potential, 2) the assets to be protected, and 3) forest locations and conditions as well as on forest growth capacities. The importance of appropriate geodata for mapping protective functions and the effects of forests are often obscured by presenting concepts, methods, and outputs of spatial hazard modeling and affected areas; however, without high-quality digital geodata (e.g., on the infrastructures to be protected, their type of use and vulnerability), protective functions and effects of forests and subsequently the natural hazard risk and its mitigation by forest cannot be determined efficiently. We introduce the main categories of thematic geodata required for protective function and effect mapping of forests and highlight specific issues linked to the use of geodata based on conceptual considerations and our experiences.

## 2. Spatial scale and the topographic baseline information

Although hazard and risk assessments can be carried out at all geographical scales depending on the intended use of the analyses [13], the mapping of protective functions and the effects of forests is mainly an issue of the spatial resolution and accuracy of the available topographical basis, especially of the digital terrain model (DTM), because of topographic characteristics such as elevation and slope control hazard susceptibility. The DTM is the key dataset for hazard assessments dictating all further steps of data acquisition and data processing, including the compilation of geodata on assets in raster and vector formats. In the case of a coarse resolution of the DTM, consideration should be given to whether it makes sense to include assets with very small footprints such as electricity pylons. They must be represented in the same resolution as the DTM in raster modeling. The coarser the resolution of the DTM, the less accurate is the hazard modeling and subsequently, the potential assets at risk are subject to larger uncertainty. Even at global levels, forest function mapping at (DTM) resolutions greater than approximately 30 m is not appropriate and limited to key infrastructure (e.g., in Europe [14]) since this is about the maximum width of main traffic infrastructures, the average width of residential units (with ancillary areas), for example, [15], and of gravitational hazards of significant magnitude. However, very high-resolution input data do not improve mapping results necessarily as shown for landslide susceptibility mapping, for example, by [16]. Very high resolutions may also be inappropriate for visualization of the results as they overstrain human capabilities of information perception and pretend that the results are highly reliable. Regardless of hazard type-specific requirements, a DTM resolution of 10 m, for example, derived from LiDAR returns based on a sample size of at least 0.2 ground classified points/$m^2$, is appropriate for modeling hazard and damage potentials to assess protective functions of forests on a regional scale. Furthermore, a 10-m resolution is suitable for the small-scale and heterogeneous land use in the Alpine Region as well as limits computation time.

## 3. Spatial data on hazard potential

To identify forests with protective functions, hazard potential indication maps for all types of natural hazards that may occur in an area, and which are clearly influenced by forest if managed properly, are required. Hazard potential indication maps are hazard maps that indicate areas, which may be affected by hazards without considering the potential protective effects of current forests or other protection measures such as technical defense structures [5]. Already including the effects of these protective green and gray infrastructures in the hazard assessment would exclude areas with protective forests or areas that are secured by technical measures, although a hazard susceptibility exists and despite potential and sudden changes of the forest conditions, for example, through windthrow.

There are five main requirements on hazard indication maps to be applied for the assessment of forests' protective functions, which are as follows:

1. they exclude all risk mitigation measures and their effects,

2. they are not limited to the observed hazard occurrence but also show the total basic hazard susceptibility due to climate, topography, and/or geology,

3. they do not only show the onset susceptibility but also the propagation probability of hazards,

4. they distinguish zones of onset (starting zone) and propagation probability (transit and runout zones) to consider different requirements on protective forest conditions in each zone dependent on the hazard type, and

5. they are based on the same ("global") scale of hazard probability.

In addition, appropriate hazard indication maps should provide at least a qualitative or preliminary zoning (ranking) of the damage potential, which is also a question of the elements at risk. The available hazard (indication) maps may not satisfy these criteria. For example, in contrast to snow avalanche and rockfall hazard maps, landslide hazard indication maps often only show onset susceptibilities (biased by data collection and forest effects [17]) based on local or regional probability scales, which are not comparable [8]. In addition, maps of permanent (deep-seated) landslides are usually difficult to interpret in terms of activity, reactivation, and zones susceptible to the influence of forest.

The methods and data requirements for producing hazard maps are described extensively in the literature, for example, in [18] for landslides and in [19] for qualitative rockfall assessments, but even the simplest approaches are data intensive. Therefore, we recommend to always critically question whether an approach is suitable for protective function mapping and if the costs for data collection are in relation to its benefits. In practice, time constraints and the availability of data and financial resources are the major decisive factors.

## 4. Spatial data on damage potential (assets to be protected)

The assets to be protected from impacts of natural hazards (hereafter referred to as "assets") are also referred to as "elements-at-risk" in disaster risk reduction (DRR) literature, which is not appropriate in any case. The latter term refers to "population, properties, economic activities, including public services, or any other defined values exposed to hazards in a given area" [20]. According to this definition, the "elements-at-risk" is a subset of assets already including the spatial intersection with the hazard potential. Therefore, the term should not be used for the selection of "goods" to be protected because of a legal or another social convention and is no longer mentioned, for example, in [21]. In the context of forest function planning, a terminology different from the DRR community is used (see also book chapters [1, 12]); that is, the assets to be protected by forest and their entities are called "objects." A simple intersection of hazard maps and assets is sufficient to identify endangered objects (the damage potential) and for risk assessment but not for delineating forests with protective functions. That is, all relevant hazard runout, transit, and starting zones uphill of the potentially endangered assets must be identified and separated from those that do not endanger assets [3, 5].

Any form of risk analysis requires to preselect the assets (objects) to be protected and included, which are types of land use or planned land use (interest in future land use) and, in the case of assessing forests' object protective functions, located outside of forests. The preselection of objects may be supported by considering the susceptibility of assets to damage and the consequences of potential loss due to the probability of the presence of people, the economic and cultural value, the physical fragility, interruptions of access, or other criteria of vulnerability such as the possibility to evacuate. Note that vulnerability is a very complex risk-related characteristic of assets including physical, social, economic, and environmental properties [13, 22, 23] (see also chapter [2] of this book). Vulnerability summarizes "the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards" [21]. Physical vulnerability, that is, the fragility of physical assets, is hazard-specific and often evaluated in the exposure assessment of the risk analysis. For example, different construction types have different physical attributes (e.g., building material of houses), but their quantitative consideration depends on the hazard type. The physical vulnerability may be the most important criteria for preselecting assets. Direct costs of damages (buildings and infrastructure) are easier to estimate and give rise to indirect costs [24]. However, selecting assets as the first step to define the protection targets for mapping protective functions of forests is ultimately and always politically driven and influenced by cultural and ideological value attitudes linked to questions of justice and regional development [5, 25].

The specification of assets may be based on legal bases that governmental hazard risk and forest management agencies must comply with. However, legal specifications do not ensure expedient registrations of assets and risks. For example, according to the Austrian Forest Act of 1975 amended in 2002 [26], people and all their infrastructures as well as cultivated land are assets to be protected by forest. The law does not contain any clauses, rules, and administrative authorizations to exclude infrastructures or land use that are of low importance, where importance translates the public interest in the preservation and use of an object for society. Therefore, the lists of assets in the administrative directive for mapping protective functions of forests included infrastructures such as forest roads and "frequently used" hiking trails, and even land uses with low vulnerability such as meadows and pastures. A debate about the asset component of risk was started when spatially modeling hazard and damage potentials to support the Austrian-wide mapping of object protective functions of forests, which resulted in the new "Hinweiskarte Schutzwald in Österreich" (indication map of protective forests in Austria, [7]). The geodata collection [27] revealed the limited applicability, risk orientation, and data reconciliation of existing geodata as well as the high-editing efforts that were required to complete, correct, and convert the available data into spatial information useful for this spatial modeling and to distinguish the protection targets according to the administrative guidelines for protective function mapping. Analyses of the Swiss [25] and Austrian [28, 29] natural hazard risk regulations also show a low coherence of the legal definitions of protection targets since there is no consensus on "the values at which a damage should be considered as a damage" in a risk context [25]. Discussions on assets and their vulnerability are often characterized by administrative traditions, anecdotic perceptions of hazards' consequences, and personal affinities, rather than by analysis of hazard inventories. Moreover, we experienced that geodata providers are often not aware of the key role their data have in natural hazard risk analyses.

The geodata and their entities about assets needed for mapping object protective functions of forests depend on the protection targets, the requirements on potential damage quantification and accuracy, and the data models. The information provided by available datasets may be incomplete or aggregated, but this can be bypassed by defining levels of spatial aggregation and comprehensiveness [27]. Furthermore, object protective function mapping may be a chance to coordinate data needs and concepts with geodata service providers as well as to complete geodata about infrastructures. Many different types of assets exist, which must be collected from numerous sources and can be classified and prioritized in various ways [13, 25]. Most of the spatial digital asset data are available in vector format since this format preserves the shape of infrastructures like buildings and road networks and meets the requirements of different administrative organizations. However, it is always recommended to consider the limitations of land use representation by different vector models and, in particular, of vector-to-raster and vice versa conversions in relation to requirements on the spatial resolution of the modeling. Most methods of risk assessment and visualization involve converting geodata from one format to another. For example, a polyline dataset of a road network can reflect the area and width of small roads at raster cell resolutions smaller than 10 m without any special adaptions, but polygon features may be necessary for the widths of highways and building footprints. Surprisingly and although GPS car navigation started by the end of the 1990s, the official (rural) road network topologies in Switzerland and Austria were proven to be incomplete and not sufficient for mapping object protective functions of forests [4, 5]. In Austria, for example, it was not systematically possible to derive the importance of the connectivity function of roads simply from the data attributes and to differentiate forest roads from local (public) access roads to inhabited settlements.

A frequently used method for determining the requirements on asset geodata appropriate for forest function mapping is to establish classes that translate the public interest in the preservation and use of an object for society. Such classes are called object classes and are often based on matrices of protection targets as, for example, proposed by BUWAL [30]. The object classes provide qualitatively determined priorities for protecting assets and subsequently prioritize the protective functions of forests. However, such lists often differ considerably. They incompletely cover the multitude of existing assets and the variety of their characteristics in terms of vulnerability as well as the information provided by the geodata.

In **Table 1**, we compare the rankings of objects (object classes) according to the Swiss BUWAL (now Federal Office for the Environment — FOEN) matrix [30], the French protective forest management guideline GSM-S [31], and the new Austrian concept for forest function mapping (WEP) based on [27]. All classification systems use a four-level ordinal scale of the need for protection from "high" (3) to "very low" (0). Although this is not clearly regulated by law, in Austria, forests with an object protective function are only allocated for object classes 3 and 2. However,

| **Asset types and entity codes of the Austrian A, French F, and Swiss S object classification system** | | **Object class (priority)** | | |
|---|---|---|---|---|
| **Settlement (residential and commercial) areas, buildings** | | **BUWAL** | **GSM-S** | **WEP** |
| S321 | Settlement area; the area/number of buildings is not defined | 3 | — | *3* |
| F11 | Settlement area, dense, more than 10 residential units | — | 3 | *3* |
| F12 | Settlement area, scattered, 2–10 residential units | — | 2 | *3* |
| A01, S231, F13 | Building suitable for residence (or multi-functional use) | 2 | 1 | 3 |
| S322, F51 | Industrial area; the area/number of buildings is not defined | 3 | 3 | *3* |
| F52 | Commercial area; the area/number of buildings is not defined | — | 2 | *3* |
| F53 | Craft business area; the area/number of buildings is not defined | — | 1 | *3* |
| A02 | Building for public service, commerce, factory, supply disposal | *3* | *3–1* | 3 |
| A03, S232, F63 | Agricultural building (in A: except hayracks) | 2 | 1 | 3 |
| A04, S324, F41 | Building for sports (recreation), cultural, religious use | 3 | 3 | 3 |
| F82 | Historical building | ? | 2 | *3* |
| A05, S325 | Valley station of a cable car (lift) connected to public traffic | 3 | ? | 3 |
| A06 | Facility area of A01–A05, building direct adjacent to A01–A05 or a facility area of A01–A05 | *3* | — | 3 |
| A27, S221 | Other buildings than A01–A06 | 1 | — | 1 |
| A07, S323 | Land designated for housing (A01–A05) or special use | 3 | *0* | 3 |
| Special infrastructure | | | | |
| A08 | Facility – supply-disposal and communication except lines and pipes | 3? | — | 3 |
| A09 | Land designated for facilities (A08) | *0* | *0* | 3 |
| A10, S234, S223, S213, F32, F33 | Above ground supply and disposal pipe | 2–1 | 2–1 | 3 |
| S234 | Overhead utility line network of national importance | 2 | 2 | *0* |
| S223 | Overhead utility line network of regional importance | 1 | 2 | *0* |
| S213 | Overhead utility line network of local importance | 1 | 1 | *0* |
| A24 | Utility pole of the high-voltage overhead line network | — | — | 2 |
| A29 | Utility pole of other overhead line networks than A24 | — | — | 1 |

| **Asset types and entity codes of the Austrian A, French F, and Swiss S object classification system** | | **Object class (priority)** | | |
|---|---|---|---|---|
| **Settlement (residential and commercial) areas, buildings** | | **BUWAL** | **GSM-S** | **WEP** |
| Traffic infrastructure | | | | |
| A11, A13, S311, F21 | Road or railroad (of national importance) | 3 | 3 | *3* |
| S233, A13, F22 | Road or railroad (of regional importance) | 2 | 2 | *3* |
| A18, S222, F23 | Road of local importance | 1 | 1 | 2 |
| A13, S222, F23 | Railroad of local importance | 1 | 1 | 3 |
| A25 | Material railway and its facility area | ? | ? | 2 |
| A32 | Forest road or road for farming (connecting to alpine pasture) | ? | ? | 1 |
| F24 | Forest road | *0* | 0 | 1 |
| S211, S212, S12, S13, F44 | Field path, hiking trail, climbing route | 1–0 | 0 | *0* |
| A12 | Parking lots | ? | ? | 3 |
| A14 | Cable car (tram) line and its facility area | 2? | ? | 3 |
| A28 | Material ropeway and its facility area | ? | ? | 1 |
| A15 | Airfield | 3–2? | ? | 3 |
| A16 | Land designated for air traffic (A15) | *0* | *0* | 3 |
| Sports, culture, and recreation | | | | |
| A19 | Cemetery, park | ? | ? | 2 |
| A20, S324, F41 | Outdoor sports facility (except the housings) | 3 | *3* | 2 |
| A21, S324, F41 | Campground | *3* | 3 | 2 |
| A22, S236, C14, F43 | Ski run, cross-country ski trail, or sled run | 2–1 | 2 | 2 |
| A23, S312, S235, F43 | Line of aerial cable car or surface lift (ski lift) | 3–2 | *2* | 2 |
| A26 | Land designated for parks or outdoor sports facilities (A19–A23) | *0* | *0* | 2 |
| Mining, disposal, cropland, pasture, forest | | | | |
| A30, A31 | Above ground mining area, open disposal/ waste processing | ? | ? | 1 |
| A33, S224, F63 | Nursery, horticulture (except gardening houses → A03) | 1 | *1* | 1 |
| A34 | Land designated for nursery or horticulture (A33) | *0* | *0* | 1 |
| A17, S224 | Cropland | 1 | *0* | 3**, 0 |
| S225 | Forest with protective function | 1 | *0* | 0 |
| A35, S214, F64 | Agricultural land use other than A17, A33 | 1 | 0 | 1 |
| S15, S16, F74 | Natural environment | 0 | 0 | 0 |

***If the soil is susceptible to wind erosion.*
*? the allocation to an entity or priority is not clear.*

**Table 1.**
*Categories and rankings of assets according to the Swiss BUWAL matrix [30], the French protective forest management guideline GSM-S [31], and the new Austrian concept for forest function mapping (WEP) [27].*

rankings of assets raise questions about legality and equality, and may not be in line with the views of property users and owners as shown by Hess [25].

Since the BUWAL rankings also include hazard (frequency and intensity) scenarios, we refer to the 30-year recurrence probability. *Italic numbers* refer to entities included in other categories of the respective system.

**Table 1** shows considerable differences between the national systems in the categorization (degree of aggregation) and ranking of objects. For example, in contrast to the Austrian system only referring to their local or higher relevance, the Swiss and French concepts distinguish infrastructures of national, regional, or local importance. In addition, the Austrian system does not differ priorities due to the number of residential units but allocates a high priority also to single residential and agricultural buildings, since this would otherwise be counterproductive to rural development objectives.

Aspects that are hardly considered when selecting and mapping assets are how to deal with future land use and limitations of geodata topicality. Protection against natural hazards (by forest) and risk assessments (but not hazard zoning) are mostly related to the currently existing assets. However, zones of land use (development) plans express interests in future land use and may also show the current use for housing more accurately than the polygons of real property cadastres [27]. That is, geodata on legal designations of building land are often also necessary to identify its current use from property data [32]. Furthermore, it is advantageous to show that future housing on building land may be tied to the protective effect of forests, which, therefore, must be maintained as a prevention measure. Therefore, forest function mapping should consider specific entity types from land use planning [27], and meaningful mapping of the object protective functions of forests may distinguish between current and planned assets.

Adapting geodata on assets to the needs of forest function mapping and risk assessment in terms of information on the vulnerability, currentness, positional accuracy, and interoperability as well as the integration of local community knowledge is still in an initial stage. Studies recommend crowdsourced spatial data complementing governmental data to improve data availability and to include local knowledge [13, 33]. However, our experiences are ambiguous in terms of data models, quality, and consistency.

## 5. Spatial data on forest conditions

The term "forest" may refer to a forest cover-based or a forest use-based forest definition. The forest cover is land currently covered by trees depending on tree height and crown cover thresholds, whereas forest use refers to all land areas that are allocated to forestry to produce forest products and benefits, and not only to areas with a current tree cover or to currently managed woody vegetation. This includes clear-cut areas without a tree cover and may include shrubland or agroforestry land, depending on the (national) forest definition. In the countries of the European Alpine Space, the forest is legally defined in different ways as an area with current forest use.

Note that there is a different meaning of the wordings "object protective function of forest," since this may also refer to other current land use than forest, and "forest with an object protective function." To identify areas with an object protective function of forest hazard starting, transit and runout zones (hazard potential) that are associated with endangering assets (damage potential) are overlayed with the current forest use as well as with the areas suitable for future forest use (growth) (see also chapter [9] of this book). Current forest use land with an object protective and/or a site (soil) protective function (see also chapters [1, 12] of this book) is legally classified as protective forest and protected from deforestation in the Alpine Space if the additional legal requirements dependent on national law are met (see [34]). It should be noted, however, that forests classified as protective forests may also have insufficient current protective effects. A map of the other land use than current forests appropriate for forest growth with an (object) protective function of forest indicates areas whose afforestation will contribute to the protection against natural hazards in the future as a nature-based solution (e.g., due to high altitude afforestation [35]).

Three basic requirements for spatial geodata sets on forest conditions can be derived from the above concept; that is, geodata need to provide information on the a) current forest use, b) capacities for forest growth also outside of the current forest use, and c) they need to be consistent with other land use information in terms of topology and interoperability. The available geodata on forest conditions often do not meet these criteria, because, for example, forest areas are mapped independently from other land use categories by different organizations, which can result in indistinct land use assignments. Furthermore, available forest layers may be based on different forest criteria, which do not always correspond to the legal forest definitions. Usually, the ability of remote sensing techniques to retrieve forest areas in line with legal definitions is limited. The often ambiguous forest criteria anchored in national forest acts hinder their full application. Therefore, we highly recommend checking the specifications of the available forest maps and the definitions that they are based on before selecting a specific map product in coordination with clients.

In contrast to forest function mapping, the protective effect of the woody vegetation, whose quantification is often the next step in natural hazard risk analyses, is not subject to forest use but an issue of the forest cover. Therefore, risk analyses that include the protective effect of forests or other woody land require information on forest cover characteristics based on appropriate spatial units (**Table 2**).

| **Characteristics of the forest (tree) cover** | **Influenced hazard types** | | | **Applicability of methods** | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Avalanche** | **Rockfall** | **Landslide** | **VIO** | **PIA** | **IEM** | **ACS** | **ACE** |
| Mean height | + | +/- | ? | L | M | M | L | H |
| Mean diameter | ? | + | + | L | L | L | L | L |
| Canopy cover | + | + | ? | M | M | M | M | H |
| Live canopy cover | + | + | + | M | M | L | H | L |
| Canopy depth | +/- | +/- | ? | L | L | L | L | L |
| Stem density | + | + | ? | L | L | L | L | M |
| Species composition | + | + | + | M | M | L | M | L |
| Area of opening | ? | +/- | + | M | M | M | L | H |
| Width of opening | + | + | +/- | M | M | M | L | H |
| Length of opening | + | + | + | M | M | M | L | H |
| Woody debris under canopy | + | + | ? | L | L | L | L | L |
| Woody debris | + | + | ? | M | M | M | L | H |

*Notes: Influence of forest characteristic on hazard types: + decisive, +/- secondary, ? not clear.*
*Methods: VIO = visual interpretation of orthoimages, PIA = photogrammetric interpretation of aerial images, IEM = interpretation of elevation (canopy height) models, ACS = automated classification of spectral data, ACE = automated classification of elevation models.*
*Direct applicability: H = high, M = medium/limited, L = low/rather unsuitable.*

**Table 2.**
*Forest cover characteristics required to assess protective effects against gravitational natural hazards and direct applicability of methods to obtain reliable and objective information.*

Little has been published on the resolution of forest geodata, that is, the minimum/maximum size of forest patches that are required to quantify the structural parameters influencing forest's protective effects, even though the strengths of key controlling factors such as the canopy cover depend on it. Note, that a "forest patch" (or evaluation unit) useful in hazard assessment does not refer to a "forest stand," which is a unit of forest management plans and may not be appropriate for that purpose [36], but to a "spatial analytical window." One concept for quantifying patch sizes is to consider the distribution of starting zone area sizes of observed hazard releases, for example, to define the minimum mapping unit of forest cover openings. However, required forest patch sizes for hazard assessments vary depending on the type of hazard.

For larger areas, information on forest cover characteristics can only be obtained by remote sensing such as visually to full-automatically deriving forest structure parameters from spectral or elevation earth observation (EO) data acquired with unmanned (UAV) or manned aircraft- or satellite-borne sensors (e.g., [37]; see also chapter [38] of this book).

A common method of EO-data collection on local to regional scales is the visual interpretation of aerial images, which is increasingly combined with vegetation or canopy height models (e.g., [39]) obtained from high-resolution digital elevation (surface) models retrieved from Structure from Motion SfM/IM photogrammetry or LiDAR. As manual measurements and polygon mapping are time consuming, subjective, and susceptible to topology errors, automated procedures using machine learning techniques are increasingly available, which show promising results (e.g., [40]). However, synoptic assessments of forest conditions in relation to their current or future protective effects require data from different sensors (e.g., [41]; see also chapters [42, 43] of this book), and often additional information from visual interpretations and terrestrial mappings (expert knowledge). The reliability of assessing (object) protective effects of forests based on EO data depends on their temporal match with the current state of the forest cover and between point/return densities of different sensors, their spatial and spectral resolution, and quality as well as limitations in representing forest characteristics by such data. Therefore, procedures to assess the protective effects of forests against natural hazards should be adapted *a priori* to the capabilities of EO data.

## 6. Conclusions

Usually, national geodata infrastructures are not organized, updated, and supervised centrally, resulting in inhomogeneous data availability, data models, and qualities, which are not yet optimized in terms of interoperability and for mapping protective functions and effects of forests. Therefore, providing adequate geodata for risk assessments by different sources and data providers is a multidisciplinary challenge and may be associated with high editing efforts [13]. However, the potential of basic and thematic geodata to be applied in various analyses is increasing at a considerable rate, for example, the focus of geodata infrastructure strategies of public administrations in many European countries is shifting from large quantity to a higher quality [44].

Ultimately, the applicability and/or acquisition of hazard, asset, or forest geodata and needed editing and modeling efforts depend strongly on the purpose and spatial scale of mapping protective functions and effects of the forest. For example, if the goal is to map the ecosystem service "protection of people and assets against natural hazards" on an Alpine (cross-national) scale, less accurate and detailed spatial information may be required and geodata from global and open-source mapping services such as OpenStreetMap can be applied, for example, in [14]. The same is true for defining protection targets and object classes acknowledging existing public interests in protecting different asset types. For example, in the Interreg Alpine Space project GreenRisk4ALPs (ASP 635) [45], we applied whenever possible (provided the input data were available) a simplified classification scheme that fits our goal of comparing modeling outcomes between Alpine Space countries and to get a first overview of potentially endangered objects in a region that can be followed by a more detailed risk assessment [11] (see also chapter [10] of this book). However, such global data and simplifications may not be appropriate for producing legally binding national maps or maps that must reflect a country's forest law or be useable for prioritization of measures and subsidies such as the maps of forests with a protective function in Switzerland [4] and Austria [7].

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