YSAS

Pixelating Forests: Remote Sensing Technologies in Forest Monitoring in Switzerland

RESEARCH

DONATA DETTWILER

ubiquity press

ABSTRACT

The paper explores the quantification and inventory of forests with remote sensing in Switzerland, by leveraging contributions of political geography related to the material and volumetric dimensions of territory. As remote sensing infrastructures are increasingly used to monitor forests and map environmental risks, they contribute to the transformation of forests into smart milieux. Focusing in particular on spatial and aerial technologies, the findings show varying infrastructural competence among cantons. The article further expounds upon the role of remote sensing in the National Forest Inventory as a vector of continuity, scalability and rationalization of forest monitoring. In conclusion, due to their rhizomatic characteristics (Deleuze & Guattari 1987), forests escape remote sensing's attempt at all-encompassing analysis.

RÉSUMÉ

L'article explore la quantification et le recensement des forêts par les technologies de télédétection en Suisse, en s'appuyant sur les recherches en géographie politique qui analysent le territoire sous l'angle de sa dimension volumétrique et matérielle. Les infrastructures de télédétection étant de plus en plus utilisées pour surveiller les forêts et cartographier les risques environnementaux, elles contribuent à la transformation des forêts en 'smart milieux'. En se concentrant en particulier sur les technologies satellitaires et aériennes, on s'aperçoit que les compétences infrastructurelles entre les cantons suisses varient de manière significative. De plus, l'article explique le rôle de ces technologies en tant que vecteurs de continuité, d'extensibilité et de rationalisation de l'inventaire forestier national. En conclusion, de par leurs caractéristiques rhizomatiques (Deleuze & Guattari 1987), les forêts échappent à l'analyse exhaustive par le moyen de la télédétection.

ABSTRAKT

Der Beitrag untersucht die Quantifizierung und Bestandesaufnahme von Wäldern in der Schweiz durch Fernerkundungstechnologien und stützt sich dabei auf Forschungen im Bereich der politischen Geographie, die das Territorium im Hinblick auf seine volumetrische und materielle Dimension analysieren. Da Infrastrukturen

CORRESPONDING AUTHOR:

Donata Dettwiler

Independent researcher

donata.dett@gmail.com

KEYWORDS:

remote sensing; forest; territory; Switzerland; quantification; volumetric

TO CITE THIS ARTICLE:

Dettwiler, D. (2022). Pixelating Forests: Remote Sensing Technologies in Forest Monitoring in Switzerland. *Swiss Yearbook of Administrative Sciences*, 13(1), pp. 1–14. DOI: *https://doi.org/10.5334/ssas.161*

zur Fernerkundung zunehmend zur Überwachung von Wäldern und zur Kartierung von Umweltrisiken eingesetzt werden, tragen sie dazu bei, Wälder in 'Smart Milieus' zu verwandeln. Der Artikel konzentriert sich insbesondere auf die Satelliten- und Luftverkehrstechnologien und zeigt, dass die Infrastrukturkompetenzen zwischen den schweizerischen Kantonen sehr unterschiedlich sind. Im weiteren erläutert der Beitrag dieser Technologien als Mittel zur Kontinuität, Skalierbarkeit und Rationalisierung des Schweizerischen Landesforstinventars erläutert. Zusammenfassend lässt sich sagen, dass Wälder aufgrund ihrer rhizomatischen Eigenschaften (Deleuze & Guattari 1987) mittels Technologien der Fernerkundung nicht erschöpfend analysiert werden können.

1. INTRODUCTION

Forest ecosystems are changing under the influence of climate change and so are the ways to quantify, map and monitor them. So-called smart cities have already attracted a large amount of scrutiny; there are, however, other smart milieux being constructed that deserve equal attention, such as *smart forests* (Gabrys 2020). In Switzerland, remote sensing technologies and geographic information systems (GIS) as interfaces, set of practices, and as a body of knowledge have been integrated in decision-making processes in environmental and urban governance since the 1990s (Walser et al. 2011). Indeed, the topic of digital technologies in forests is increasingly debated among professional forestry actors. For example, July 2021's issue of the established scientific journal *Schweizerische Zeitschrift Forstwesen* was entirely dedicated to 'Digitalization and change in the forest' (Rutishauser 2021). The study thus proposes to investigate remote sensing objectivation of forests in Switzerland. It will do so by introducing the volumetric strand of geographical research to administrative sciences.

The velocity and scope of climate change's impacts are a growing matter of political, economic and scientific concern in forest governance. In Switzerland, environmental science and environmental policy circles should not be understood as two separate social domains. This is demonstrated by the National Forest Inventory (NFI) workflow – a decade-long, joint project between the Swiss Federal Office of the Environment (FOEN) and the research institute Forschungsanstalt für Wald, Schnee und Landschaft (WSL) actors. Forest ecosystems' transformations are difficult to reactively assess through established on-the-ground inventory practices (Zürcher-Gasser et al. 2016). Hence, it is worthwhile to examine the political-economic rationality underpinning environmental technologies, as they are leveraged in forest ecosystems monitoring in the imbricated policy-science interface. Thus, this article addresses the following questions: *How are remote sensing technologies contributing to defining the territorial concept of forests? In which ways is remote sensing inscribed in Switzerland's forest governance?*

Taking on the invitation of Elden (2013) to engage with the materiality of territory in its three-dimensionality, the following study considers how remote sensing assemblages come to inscribe geo-physical forests, considered not only in their extensions (as areas or lines on a map) but in their depths and ambient characteristics, perpetually engaged in a process of transformation and becoming (Gordillo 2018). Switzerland's forest governance is a worthwhile case study as it is structured by organizational and spatial specificities. Firstly, its long-standing history of forestry planning and sustainable management dates back to the mid 18th century (Ortloff 1999). Secondly, Central European forests' ecological structures are not as homogeneous as artificial plantations, making forests in Switzerland less easy to systematize through scientific models and satellite's pixel resolutions. In addition, in non-plain regions the sloped terrains constitute a challenge for active radar signals to reliably digitally inscribe multidimensional terrains (Parkan 2019). In that, the case study challenges volumetric remote sensing mobilization, both given its established forestry field and its topographical constitution.

To investigate remote sensing forest monitoring, the article will present a theoretical background on the presence of technologies in environmental governance literature, the growing attention to volume in thinking territory and Switzerland's forest monitoring processes. Taking stock of a qualitative methodology, the results aim to better discern how remote sensing contributes to new social interactions that ensure the quantification of forests and, in the process, how they

DOI: 10.5334/ssas.161

shape forest territory both as socio-technical ecologies and as political technologies themselves (Gabrys 2020: 7; Elden 2010).

2. THEORETICAL BACKGROUND

2.1. ICTS IN ENVIRONMENTAL GOVERNANCE

In 2019, a group of remote sensing researchers put forward a global tree restoration plan based on satellite data, recommending the planting of approximately 1 billion hectares of trees worldwide to reduce anthropogenic CO_2 emissions by two thirds (Bastin et al. 2019). The promising climate change mitigation solution was, however, followed by expeditious rebuttals (e.g. Friedlingstein et al. 2019; Gabrys 2020). Beyond discussing the merit and demerit of such a proposal, this public controversy showed that the policy ramifications of remote monitoring systems necessitate further attention. Other than instrumental or deterministic accounts, information and communication technologies (ICTs) in forest and, more broadly, in environmental governance constitute an understudied topic of social sciences research (Rothe 2017; Bakker & Ritts 2018; Olbrich 2019). This article aims to bridge this gap and will conceptually leverage the literature on the vertical and volumetric dimensions of territory put forward recently by political geographers (Bridge 2013; Elden 2013; Goldstein 2020).

ICTs participate in the reconfiguration of new modes of contemporary forest governance, characterized by decentralization, greater non-state actors participation and marketization (Arts & Visseren-Hamakers 2012; Goldstein 2020). Forest environments are increasingly becoming smart milieux, as interfaces of data collection processes through a host of technical artifacts and computational practices. Further, they are being framed as technologies themselves for their ability to fix important quantities of atmospheric carbon in climate change mitigation strategies (Gabrys 2020). Remote sensing technologies have contributed to transforming forests and other ecosystems into sets of inscriptions to be transported, read and reassembled in centers of calculations (Latour 2005; Latour 2017). Wider availability and commercialization of Earth Observation (EO) images has occurred in *co-evolution* to the growing environmental security discourse (Rothe 2017). Visual assemblages made of remote sensing and computer modeling 'turn "nature" into a range of calculable, perceivable, and governable risks through a series of calculations, transformations, and translations' (ibid.: 338). In so doing, the increased use of remote sensors has been criticized for attempting to make fungible the incommensurable complexity of forested environments (Vidalou 2017). Such translating endeavours sustain the valuation project of ecosystem services, which aims at internalizing the negative externalities of environmental degradation by monetizing ecosystems' goods and services benefiting human societies (Rothe & Schim 2018; Tordjman 2021). Although environmental monitoring assemblages have markedly increased, a significant amount of information remains unprocessed, a state in potentiality referred to as *dark data* (Bakker & Ritts 2018). As such, greater environmental data disposal does not lead to more equitable governance. Their modes of collection and application in environmental monitoring have, however, highlighted the continued relevance of territorial institutions and bordering practices (Dalby 2020; Sassen 2013; Goldstein 2020).

2.2. THE VOLUMETRIC SHIFT IN TERRITORY RESEARCH

GIS has early on been understood as a new management instrument to further the state's historical legibility enterprise (Scott 1998) by digital means (Walser et al. 2011). A monitoring infrastructure that risks invisibilizing local conceptions of environmental processes (Parks 2005; Robbins 2001). With the integration of digital technologies in administration procedures, novel inter-organizational communities of practice have emerged in territory planning (Noucher 2009). They have dealt with controversies, conceptual ambiguities, and new regulations, forming more or less stable assemblages integrating more-than-human entities. Away from an understanding of territory as a bounded, static space, geographers have stressed its historical genesis as a modern organising concept (Elden 2010; November, Camacho-Hübner & Latour 2010). In that, territory is a perpetual process, re-made and re-contested through technical, legal, strategic and economic techniques (Elden 2010; 2017). For example, in Switzerland, the pertinence and means to centralize geodata production is a matter of ongoing legal, technical and industrial innovation debates (e.g. see Fahlbusch 2016; Benoit-Godet 2021; Kaul 2019). The territorial project is thus composed of three imbricated components: spatial ideas, practices, and material technologies, which increasingly include remote sensing technologies such as drones (Branch 2017).

The vertical, volumetric and voluminous dimensions of space have emerged in political geography as an issue relating to contemporary forms of *geo*political control (Elden 2013; Goldstein 2020). Volumetric calculative techniques are part and parcel of territorial rationality. Knowledge on volumes (encompassing subterranean, above-ground and aerial dimensions) are integrated into economic and strategic purposes. '[V]olume is a primary metric of anticipation and potential: calculations of what space contains (cubic meters of gas, ounces of gold), and what contained materials mean that space could become, are essential to the performance of resource landscapes' (Bridge 2013: 56). Research in forests has also growingly investigated the subterranean forms of life. Health of forests and their ability to resist droughts depend not only on trees as stand-alone units but also on underground rhizomatic mycorrhizae networks ensuring transfer of nutrients, water and messenger molecules between plants (Pickles & Simard 2017). By considering the volumes of forests we complexify the definition of these ecosystems.

With monitoring technologies having higher resolution coupled with greater computational models, the issue of metabolizing all these volumes of information (Boyce 2016)—thus attempting to shed light on the inherent *opacity of terrains* (Godrillo 2018)—has become a significant administrative and technical issue. Here spatial resolution is defined as the size of the standard pixel unit, which is possible to display in various forms (numbers, graph, etc.), given the rheology of data (Menkman 2019). In Switzerland, cantonal police departments use drones to attempt to enrol the vertical perspective for surveillance purposes. Officers come to contend with the materialities of volumetric spaces (fog, built environment etc.) resisting their prosthetic vision (Klauser 2021). Goldstein (2020) has applied this new research dimension to satellite's surveillance of forest fires. She shows the resolution of the National Aeronautics and Space Administration's (NASA) Landsat does not permit a precise location of undeground fires' origins, leading to transnational controversies in assigning blame. In this regard, the analytical move to *thinking with volume* (Elden 2013) is inseparable from a careful investigation into the contingent sociotechnical assemblages factoring in volumetric quantifications.

2.3. MATERIALIZING FORESTS IN SWITZERLAND

'Data are intertwined with practices, responses to perceived problems, modes of materializing and evidencing problems, and anticipations of political engagement', writes Gabrys (2016: 159). Following the Forest Dieback scientific and political controversy in the 1980s, the Swiss federal administration commissioned a series of long-term forest researches including the NFI, mandated to the WSL from the beginning in 1983. It is now in its fifth iteration, having published the fourth NFI results collected between 2009 and 2017 (Brändli, Abegg & Leuch 2020). NFI developers have added a greater variety of social and ecological modules in conjunction to the forest federal policy diversifying forest functions and integrating international forest policy prerogatives, notably on biodiversity and sustainable forest management (Lieberherr & Thomann 2020; Küchli & Blaser 2011). Nonetheless, the NFI quantitative definition of forest has remained unchanged and the statistical aggregative method has continued to be fundamentally based on the same sampling spots since the second NFI. It defines forest quantitatively as: a ground surface covered at 20% by tree crowns, 50 meter wide and with trees or shrubs higher than 3 meters (Brändli, Abegg & Leuch 2020: 2). Cantonal legal forest definitions don't all follow the same indicators although a third of self-reported forest cantons use NFI results without further complementary surveys (Gollut & Rosset 2018: 16). Through the editions, NFI officers have integrated a wider range of remote sensing technologies for more qualitative assessments beyond recognition orthophotos. As new sensors are integrated in forest monitoring, how they come to make legible ecosystems and participate in the qualification of forest processes needs further inquiry.

Forest volume monitoring is thus closely intertwined with growing political importance of ecological forest functions and changing land use (Bachmann 2005; Rigling et al. 2015). As timber prices decrease due to multiple socio-economic factors, ensuring forest multifunctionality has been put on the political agenda (Fässler 2020). Communes and cantonal pilot projects have compensated forest owners for forest services rendered, mainly for air filtering, carbon sequestration and tourism (Rey 2014; ForêtSuisse 2020). In that, forest policy is interrelated to other territorial processes, which go beyond Swiss borders (Elden 2010), influencing strategic interests framing forests not only as a timber production location but also as a habitat for endangered species and a place of recreation. Knowledge on forests has contributed to a greater legibility of forest environments on the part of State and private actors, which are, however, challenged by the rapidity and difficulty to predict and react to climate change (Rigling, Landolt & Manser 2015).

To sum up, standardized practices of monitoring forest changes have participated in their integration into territorial rationalities, imbricated in decentralized forest governance (Küchli & Blaser 2005). Territory as a political technology is a process perpetually in-the-making constituted by an ensemble of situated and partially conflicting legal, economic and technological regimes. In this, deterritorialization and reterritorialization (Deleuze & Guattari 1987) are precious notions to denaturalize territory and examine 'to what extent things remain in place' (Elden 2005: 10) through these regimes' bordering capabilities (Sassen 2013). New geospatial technologies hold considerable potential to transform ideas, practices and technologies of the territorial project in Switzerland. Researchers highlight how remote monitoring outputs are leveraged in attempts to control volumetric resources and territorialize forests, which resist total quantification given their material complexity.

3. METHODOLOGY

The present research questions relate to remote sensing forest volume objectivation in Switzerland. The research methods adopted include semi-structured interviews, extensive review of federal forest policy documents and monitoring literature, available cantonal forest department organograms, three email exchanges with FOEN and Swiss Federal Statistical Office (OFS) appointees and participant observation during a one-day marteloscope class.

This present research was done as part of an unpublished master thesis. It was informed by 15 semi-structured interviews with eighteen Swiss forest governance actors, the majority of which were found through online research and contacted by email. The initial informants referred the remaining contacts. The qualitative method employed was used to record the trajectories of technological expectations (Borup et al. 2006; Olbrich 2019), which are difficult to understand with more quantitative methods of analysis. Future technological visions are the 'real-time representations of future technological situations and capabilities' (Borup et al. 2006: 286) informed by situated techno-political obstacles. The interviewees were: ten remote sensing analysts—three persons working for private remote sensing companies, five individuals from research institutes (e.g. WSL) as well as two practitioners employed in cantonal forest offices—; one software developer; three forest engineers; one federal policy-maker, one biodiversity conservation specialist and two forest owners representatives. The interviews were conducted from end of May 2020 to mid-August 2020 and ranged in duration from 51 minutes to three and half hours. Due to the COVID-19 pandemic, six of the interviews were done remotely, three by phone and three by Skype. 12 of the interviews were recorded with the permission of the interviewees.

Three of the interviews were conducted in French, eight in English and four in Italian, and this has called for translation efforts on the part of the interviewees, who for the most part were German-speaking natives. Following an exploratory stage, the open-ended questions structuring the interviews focused on three main axes: the possibilities and practical limits of remote sensing data to monitor forests ecosystems and functions, the forest governance actors they interacted with, and, finally, the informants' perception of sustainability in forests. Once the interviews were conducted and transcribed, the software Atlas.ti was leveraged for qualitative data analysis. 31 codes were developed deductively, which referred to 'remote sensing technologies', 'forest definition', 'human vision', 'error' etc. that allowed in a second stage to associate different codes to create taxonomic tree structures around three main themes: volume; multi-functionality and forest functions; governance.

The narrow focus on Switzerland runs the risk of falling into the 'territorial trap' (Agnew 1994), reifying territory to a bounded space and obscuring the associations with other centers of calculation. That being said, STS contributions (Latour 2005; Callon 1984; Law & Mol 2001) with respect to deterritorialization and reterritorialization of networks is useful to overcome this methodological nationalism (Beck 2007). The article will now turn to discuss the findings related to the administration of dark data, the commensurability of remote and on-the-ground perspective, and how remote sensing attempts to inscribe forest functions.

4. FINDINGS: AN IMAGE CAN HIDE A FOREST

4.1. ADMINISTRATION OF DARK DATA

Remote sensing technologies are increasingly part of the territorial project in Switzerland. However, there is a significant inequality between cantons in infrastructure competence (Sawyer, Erickson & Jarrahi 2019) to collect and process the data, so much so as to be referred to a 'Swiss patchwork' by an interviewee. For example, canton Aargau is considered a referential canton, in terms of in-house cantonal flight, quality of remote sensing data and open data policy. Among other cantons, Bern, Zurich, Lucerne have their specific GIS departments working on a variety of management themes. Canton Wallis has commissioned valorisation research projects of Swisstopo data, which has fewer metadata available as cantonal flights but is less costly (Monnet, Mermin & Dupire 2016). Tessin does not have a specific GIS forest team and does not commission LiDAR campaigns, preferring to translate the statistically significant NFI results for cantonal management. Albeit non-exhaustive, these findings indicate an unequal cantonal propensity toward remote sensing enrollment. This process depends on the canton's economic resources, availability of operational methods and topography as well as presence of foresters particularly interested in these socio-material issues. In that, the associations making possible remote sensing in forest monitoring are not stabilized and black boxed.

Possible centralization of geospatial forest information is a matter of ongoing debate. To interpret geospatial data, research-administration innovation projects are organized. Researchers get access to dark data and in exchange produce a user-friendly product or information useful for territorial management. These cross-organizational initiatives, still limited in time and deliverables, could be institutionalized in the form of a common national platform (Rath et al. 2021). At the national scale, the NFI has long leveraged remote sensing technologies and constitutes a stabilizing institution in forest policy debates. Remote sensing applications in the NFI workflow have increased in the last 10 years. Currently, the NFI employs space-borne technologies (predominantly NASA Landsat, Sentinel and private Planet), governmental Swisstopo and private aerial photographs, LiDAR datasets produced by certain cantons as well as in-house drone images.

A significant possibility afforded by remote sensing, particularly EO, is to propose a rapid, repeatable overview of forests, less detailed but more frequent and standardized than ground view. A perspective sought to monitor variations related to climate change, which are increased in frequency (e.g. recurring droughts) and impact. In this sense, interviewees discussed remote sensing in the NFI setting in relation to scalability, as a way to cover larger forest coverage albeit with diminished precision. This constitutes an incremental reform, as the NFI can be regarded as a project of scalability from its inception by relying on statistical methods.

4.2. DON'T BELIEVE THE HEIGHT: COMMENSURABILITY OF MEASUREMENTS IN THE NATIONAL FOREST INVENTORY

Remote sensing allows for nonhuman visions to be integrated in forest management. Multispectral resolution is increasingly leveraged for studying the health of forests and water stress as an institutionalized practice. They are able to inscribe invisible processes to the human eyes, relating to chlorophyll activity indicative of vegetation and water stressed plants. Currently not all forest characteristics – particularly those underground and under the canopy – can be directly assessed through aerial and spaceborne remote sensing. Remote sensing research is still ongoing to infer missing elements through proxies and models (e.g. Damm et al. 2020). The guiding technological delegation principle in the national inventory process is to reduce measurements that are approximated visually by expert judgements. Visual interpretation is difficult to reproduce by another person, as it is not automatized and criteria of judgment are more or less formalized. In that, remote sensing delegation underpins the project of further rationalization of forest inventory. In consideration of the NFI, the added challenge is to ensure the paramount prerogative of continuity and comparability between editions, making sure the forest change recorded isn't due to variation in measurement method.

With the increased reliance on remote sensing technologies, the challenge of stitching together ground and remote view has been amplified. One private remote sensing analyst explained: 'It's something you really need to be in close contact with [forest officers] to try to understand what are their definitions and their categories and then try to find categories that could fit to their categories and what you cannot see'. On-the-ground decisions rely on the integral perspective of foresters (Zürcher-Gasser et al. 2016). Silviculture attention is particularly focused on individual trees and their relation to one another in terms of light and distance (both in the understory and at canopy level), a spatiality that is not aligned with that of satellites' pixel sizes. While forests can be seen in their entirety at a glance from outer space, the single tree in close forest is invisible to the satellite gaze (Schim 2014), rendering individualization processes like tree selection difficult. Whereas from a ground perspective, the trees are visible to human eyes but not the entirety of the forest. As the resolution structures the prosthetic vision, the categories of seeing require a work of translation of the categories of perception among actors.

Remote sensing is increasingly leveraged from forest area delimitation towards more qualitative and three-dimensional assessments (border forms, height of trees, tree volumes, etc.). Beyond the flat cartographic imagination so prevalent as a spatial idea of territory (Elden 2013; Branch 2017), remote sensing accounts for volumetric information. Specifically, in Switzerland, LiDAR is a prominent three-dimensional instrument. Vertical calculative techniques are apparent in assessing tree height with aerial LiDAR and border voluminous sinuosity as well as quantifying potential for timber volume in a forest. In contrast to EO, human expert vision is easier to integrate with laser scanners. A private remote sensing analyst explained, LiDAR data 'are really close to what you can see […] and it mainly gives information for the management because you get the height and you get a bit the crown dimension and the volume of the stem, that's what they want'. The established vertical forest management categories influence the choice of certain remote sensing assemblages.

4.3. TERRITORIALIZING THE VERTICALITY OF REMOTE SENSING

Remote sensing infrastructures monitoring forests and mapping environmental risks contribute to the quantification of terrains and rationalization of forest inventories. However, modelization of forest functions is still a matter of scientific controversy. Remote sensing datasets face multiple uncertainties, varying in importance and rationale. Mountains, particularly forested, continue to pose a challenge to remote sensing. Due to their steepness and atmospheric characteristics, skewing active and passive sensing signals, they constitute significant opaque terrains.

From a management perspective, quantifying forest functions is important for strategic and operational decisions. However, forest functions are not all equally quantifiable through remote sensing. Certain forest functions (timber volume, protective forests, biodiversity) are easier to model than others (especially forest as a place of leisure). The morphological and spectral characteristics of forested volumes can inform whether a forest is water stressed, structurally diverse, healthy etc. In this sense, remote sensing doesn't objectify all the 'sweet tidbits of existence' in a forest (Oliver 2014: 37). Only through calculative aggregations remotely sensed measurements are transformed into decision-making information. However, it is a work in progress. Human beings' appreciation of an environment is difficult to objectify using remote sensing methodology, although ensuring the recreational function of forests is a growing dimension of forest management. A WSL researcher commented: 'with the remote sensing we can detect these areas, we can describe these areas, we can map these areas, but then the link from the pattern to the process, this is still very much open'. Forest functions are more or less easy to assess using remote sensing depending on processes' spatiality and spectral properties as well as computational products available.

When it comes to modeling Central European forests such as those maintained in Switzerland, one of the issues is the de- and re-territorialization of algorithms produced in other contexts, with different sets of controlling observations and assumptions. In particular, algorithms for calculating biomass information produced with and for plantation forests in Scandinavia are not necessarily adapted to be applied to more heterogeneous forests. The process described here

DOI: 10.5334/ssas.161

underscores the hidden territoriality of algorithms. Models which are produced in one center of calculation for predictable plantation forests; they cannot be copy-and-pasted in Switzerland, where a different history of forest management has contributed to less homogenous forests. As Tsing (2012: 510) has put it '[p]lantations gave us the equivalent of pixels for the land' as they are 'models of scalability'. Here we reach a limit of remote sensing's scalability possibilities in Switzerland as near-natural environments escape total legibility. This constitutes an other obstacle to remote sensing cantonal enrollment to quantify resisting terrains.

Analysts are ever mindful of having to navigate the socio-technical network of remote sensing. The decision to use specific methodologies implies certain epistemological assumptions; this is also the case for the work involving different types of images (aerial LiDAR; satellite imagery, historical photography, etc.) (Vertesi 2014). A WSL researcher explained the choice of a technology with a driving analogy:

> 'Depending on what you want to see you have to adapt to the image you have [...] it is like saying which is the ideal car to use? The tractor is better if you need to bring hay for 2 km. If you are moving houses, a truck is better, but if you have to take a long trip, a *Sedan* is better. If you have to go very fast, a *Ferrari* is better. That is, everything has its ideal use–there is no perfect photo for everything'.

A researcher working on automatizing tree inventory also drew a parallel between choosing an image and driving. To explain how a routing algorithm functions to categorize trees, the interviewee associated three phenomena, a) a Global Positioning System's (GPS) assemblage finding the quickest route in a network of roads, b) tree structure growing to photosynthesize sunlight and distribute nutrients with minimum energy, and c) a child drawing a tree. These analogies speak to a navigational understanding of remote sensing technology selection, drawing on figures of speech related to driving and efficiency. They further underpin the arborescent rationale present in computation models, and are indicative of a cognitive map of volumetric ambient conditions (distance, light disposition, steepness, etc.). These driving images thus highlight the territorialization at play in environmental scientific knowledge production with remote sensing.

5. DISCUSSION AND CONCLUSION

5.1. DISCUSSION

The possibilities of coming to know forests with remote sensing assemblages rests on a chain of translations relating measurement devices, classification operations and aggregative endeavors (Mennicken & Espeland 2019). Knowledge is 'rather than a picture or representation of reality, it is *a map of what reality allows us to do*' (Glasersfeld 1991: 3 [emphasis in original]). To further this metaphor of knowledge as a map, we may thus say the work in remote sensing centers of research is a navigational enterprise. It seeks to mobilize previously disparate entities together to provide a continuous assessment of the state of forest ecosystems according to functions reflecting current social, economic and political concerns.

The technologies and organizational principles framing forest monitoring at the national level are inscribed in the state institutions' preoccupation with continuity, particularly prominent in the NFI technological delegation process. Researchers have started to combine remote sensing and deep-learning models to propose wall-to-wall maps relating to, for example, height models and abundance of main tree species (Rath et al. 2021; Ginzler & Hobi 2015). These are as of the fourth NFI, addendum products to the NFI statistical tables. They are, however, significant results as they are continuous for Switzerland, rather than sample based, and more frequently updated than the core NFI analysis. This continuity is possible only through the stabilized enrollment of a wider network of actants that supersede Swiss borderlines, as EO data mainly used in Switzerland are from the ESA, NASA, and international private firms. However, the possibilities of GIS are not fully realized at the moment, with remote sensing constituting a controversial subject questioning the 'geography of responsibilities' (Akrich 2006: 162) presently structuring forest inventory practices.

The findings have shown that not all cantons have specific LiDAR flight campaigns, in-house GIS employees and geospatial units nor frequent interactions with remote sensing researchers

DOI: 10.5334/ssas.161

- an inequality which has an incidence on the national process. The NFI collects certain canton-based aerial LiDAR information for its own analysis, as not all cantons have the same high-resolution monitoring of their forests, this makes for a patchwork overview. In that, cantons with more forests are not necessarily the ones with more detailed environmental information. The issue of dark data is another significant organizational challenge, further accentuating cantonal inequalities with regards to the digital transformation of the territory. Remote sensing assemblages in forests are thus creating new, relatively enduring connections among otherwise separated sites: centers of calculations, state offices, research institutes and cantonal departments. These assemblages in turn border actors, which may not be as infrastructurally competent in digital geospatial technologies.

Forest monitoring assemblages mobilize a host of measuring devices and human and non-human ways of seeing. Human integral observations in forests are epistemologically different from computational visualizations, in their referential traceability (Latour 2014), chromatic range and affective formation. Understanding what one is seeing in a forest is a learning process involving tacit and embodied knowledge taking place over years of professional activity (Parkan 2017; Zürcher-Gasser et al. 2016; Gartmeier et al. 2008). In this regard, the analysis considered the translating and negotiating skills at play in collaborative projects between remote sensing analysts and non-GIS specialists. In this, remote sensing cannot supplement the work in situ, as there are parameters that are invisible or approximated through prosthetic vision. For example, diameter at breast height is a volumetric indicator that is more accurate when calculated on the ground. In this sense, remote sensing in the NFI setting faces the challenge of moving from sample-based technique to a more continuous, scaled up extension whilst maintaining the comparability of result between inventories.

Uncertainty is a recurring dimension of remote sensing interpretation seeking to quantify and qualify forest multiple volumes. The rhizomatic characteristics of forests (multiple, continually in a state of becoming, partially underground) and the heterogeneity of their ambient and volumetric characteristics constitute obstacles to computational predictions of forest processes. The findings have demonstrated that opacity of terrains manifest itself not only in militarized settings (Boyce 2016; Godrillo 2018) but also in forest monitoring, especially steep mountains.

Moreover, the study contended with functionalist definitions of forests. In Switzerland, forests are defined quantitatively and qualitatively by the forest functions ensured (Bončina, Simončiča & Rosset 2019). These are not all possible to assess with remote sensing. The process of classifying pixels highlight that remote sensing definitions of forest can differ significantly from political classifications (Vandergeest & Peluso 2015), which in Switzerland are found to be particularly multiple and stratified (belonging to forest owners, cantonal or national authorities, NFI, etc.) (Walker & Artho 2018). In this regard, EO has been considered for a long time as too low resolution for monitoring forests in Switzerland. With the 2015 Sentinel-2 (with a pixel resolution of 10 x 10 meter) EO has progressively been evaluated as a possible operational instrument for cantonal forest management. In collaborative innovation projects, the controversy over the definition of forest is partially re-open in consideration of how to align on-the-ground and EO categories of forests. In practice, it is not necessarily closed, as with other environmental boundary objects such as wetlands (Harvey & Chrisman 1998), a strong definitional consensus of forests is not paramount to collaborate with GIS analysts.

Gabrys (2020) perceptively noted that forests are increasingly framed as carbon-stocking technologies to be managed in consideration of climate change mitigation strategies. Although significant differences do exist, forests in Switzerland have historically been considered as risk infrastructures before the carbonification of environmental discourse that has structured forest definitions in the last decades in international policy-making circles (Chazdon et al. 2016). Namely, the understanding of forests as technologies is evident if we consider the territorial framing of mountainous forests as serving a protective purpose that is substantially infrastructural; as avalanche barriers shielding villages in the valley, for instance. In that, forest functions are inscribed into a social mode of organizing space that extends beyond the forest borderlands and as such, participate in the political technologies of territory.

The metrics of calculating volumes relate to the valuation of resources (McNeill 2019). The technological standardization of forest definition and the corollary quantification of forest cover through remote sensing monitoring better enables the transnational financialization

DOI: 10.5334/ssas.161

of forests categorized as commodifiable carbon stocks (Rothe & Schim 2018). In Switzerland, in contrast, the economic products of forests are found in timber selling and increasingly in monetizing the function of leisure on the part of cantons or communes (Rey 2014), which is however less modelizable with remote sensing information – a limit of these technologies as decision-making instruments. Accordingly, depending on which forest provision is integrated in economic markets, remote sensing environmental quantification may be more or less useful to this economic appraisal project.

Noteworthily, digital documentation of three-dimensional spaces in Switzerland is not limited to forests. As urbanization increases land pressure, federal cartography administration is integrating GIS to survey vertical condominium property and underground spaces (Ruth et al. 2013; Åström Boss 2019). The air and belowground become further terrains to be measured, regulated and planned, as in other urban places such as Singapore (McNeill 2019). Below ground in forest is difficult to study with aerial and space remote sensing, however, radar technologies are increasingly available to normalize this space (Märki 2020). In this context, the focus on volumetric quantification allows us to compare urban and forest materialities going beyond nature-society dichotomies (Descola 2005) to engage with the role of quantification in the politics of resource exploitation.

5.2. CONCLUSION

The article considered how remote sensing technologies participate in the vertical and volumetric calculation and visualization of forests in Switzerland. As these technologies are integrated into the calculative regime of forest monitoring, analysts enrol new practices of measuring space in step with the state's project of legibility. Following a Foucauldian framing, we can understand technologies as 'manifest[ing] in three major forms: as utopian impulse, institutional practice and academic discipline' (Matthewman 2013: 3). This three-pronged definition can also be applied to remote sensing infrastructures, as an utopian impulse (e.g. the promise of global transparency in monitoring and measuring environmental policies) and as an institutionalized practice (by state and non-governmental actors) as well as, increasingly, an established academic discipline. Scientific knowledge that is produced with remote sensing contributes to a more frequent, detailed 'synoptic view' (Scott 1998: 2) of forest governance actors that are able to rapidly monitor the changes occurring in forests, e.g. localizing water-stressed trees during a drought. In this, remote sensing technologies participate in the greater imbrication of the science-policy interface at the national level with the NFI and in a more limited manner in cantons.

The present research contributed to the understudied discussions on technological integration in forest governance in Switzerland. The political and administrative relevance of remote sensing lies in its capacity to quantify forest functions, which inform the role these ecosystems play in territorial planning. In the forest policy agenda, these have historically changed to integrate more prominently non-timber production functions, which are not, for now, all readily modelizeable with remote sensing indicators at a scale useful for operational decision-making. NFI officers have increased for each edition their reliance on remote sensing technologies in order to rationalize, scale up and increase the continuity of measurements, leading to controversies over which parameter to delegate to remote sensing and which to keep in situ. Further, remote sensing analysts have emphasized the uncertainty related to aggregative operations translating spatialized vertical information of trees to land processes. This is due to the complexity of heterogeneous forests maintained in Switzerland, the challenge of re-territorializing algorithms produced in another controlling environment, and the difficulty to predict climate change effects on forested ecosystems (Brändli, Abegg & Leuch 2020). Moreover, the research demonstrates the limits of framing remote sensing as panoptic infrastructures, as forests, by their compositions and continual transformations, continue to elude technological all-seeing scrutiny.

There are methodological limits to the study, given linguistic, organizational and resource constraints. There is a bias in the self-reporting and available documentation, obtained primarily online. In addition, forest enterprises were not consulted, albeit they have their own inventory practices that may include remote sensing (Schlaepfer 1985; Bachmann 2005). Not all cantonal forest offices were consulted given the focus on the NFI workflow. To conclude, further research on how technologies influence territorial ideas, practices and mechanisms of control is needed. In particular, the ways in which digital spatial information increases or prevents public participation in forest decision-making is a central question. In Switzerland, greater scholarly attention should be given to the science and policy interface, especially in consideration of the historical influence of environmental matter-ing debates (Moser 2008) such as the Forest Dieback controversy in the 1980s, and presently the saliency of climate change. Additionally, it would be worth leveraging participant observation to study how the recursive interactions between analysts and software unfold and consider the strategies of reducing uncertainty among actors.

ACKNOWLEDGEMENTS

I would like to extend my appreciation to the two anonymous reviewers for the valuable comments, which helped concise the argument, and to Daniel Stefan Kükenbrink for the attentive reading and helpful annotations.

COMPETING INTERESTS

The author has no competing interests to declare.

AUTHOR AFFILIATION

Donata Dettwiler *orcid.org/0000-0002-5147-7146*
Independent researcher

REFERENCES

Agnew, J. (1994). The territorial trap: The geographical assumptions of international relations theory. *Review of International Political Economy*, *1*(1), 53–80. DOI: *https://doi.org/10.1080/09692299408434268*

Akrich, M. (2006). La description des objets techniques. In M. Akrich, M. Callon & B. Latour (Eds.), *Sociologie de la traduction. Textes fondateurs* (pp. 159–178). Paris: Presse des Mines. DOI: *https://doi.org/10.4000/books.pressesmines.1197*

Arts, B., & **Visseren-Hamakers, I. J.** (2012). Forest governance: Mainstream and critical views. Moving Forward with Forest Governance. *ETFRN News*, *53*, 3–10.

Åström Boss, H. (2019). 3D-Stockwerkeigentum - Technisch bereit, *3DGI 2019 - Internat. Fachtagung zu 3D-Geoinformation FHNW Muttenz*. Retrieved from: *https://www.3dgi.ch/*

Bachmann, P. (2005). Forstliche Planung – heute und morgen. *Schweiz. Z. Forstwes*, *156*(5), 137–141. DOI: *https://doi.org/10.3188/szf.2005.0137*

Bakker, K., & **Ritts, M.** (2018). Smart earth: A meta-review and implications for environmental governance. *Global Environmental Change, 52*, 201–211. DOI: *https://doi.org/10.1016/j.gloenvcha.2018.07.011*

Bastin, J. F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M., Routh, D., Zohner, C. M., & **Crowther, T. W.** (2019). The global tree restoration potential. *Science, 365*, 76–79. DOI: *https://doi.org/10.1126/science.aax0848*

Beck, U. (2007). The Cosmopolitan Condition: Why Methodological Nationalism Fails. *Theory, Culture & Society*, 24(7–8), 286–90. DOI: *https://doi.org/10.1177/02632764070240072505*

Benoit-Godet, S. (2021, june 29). Vue depuis l'espace, la Suisse, c'est une seule vallée. *L'illustré*, 58–60.

Bončina, A., Simončiča, T., & **Rosset, C.** (2019). Assessment of the concept of forest functions in Central European forestry. *Environmental Science and Policy*, *99*, 123–135. DOI: *https://doi.org/10.1016/j.envsci.2019.05.009*

Borup, M., Brown, N., Konrad, K., & **van Lente, H.** (2006). The sociology of expectations in science and technology. *Technol. Anal. Strat. Manag., 18*, 285–298. DOI: *https://doi.org/10.1080/09537320600777002*

Boyce, G. A. (2016). The rugged border: surveillance, policing and the dynamic materiality of the US/Mexico frontier. *Environment and Planning D: Society and Space*, *34*(2), 245–262. DOI: *https://doi.org/10.1177/0263775815611423*

Branch, J. (2017). Territory as an institution: spatial ideas, practices and Technologies. *Territory, Politics, Governance*, *5*(2), 131–144. DOI: *https://doi.org/10.1080/21622671.2016.1265464*

Brändli, U.-B., Abegg, M., & **Leuch, B. A.** (Eds.) (2020). *Inventaire forestier national suisse Résultats du quatrième inventaire 2009–2017*. Bern and Birmensdorf: WSL/FOEN. DOI: *https://doi.org/10.16904/envidat.147*

Bridge, G. (2013). Territory, now in 3D. *Political Geography*, *34*, 55–57. DOI: *https://doi.org/10.1016/j.polgeo.2013.01.005*

Callon, M. (1984). Some elements of a sociology of translation: Domestication of the scallops and the fishermen of St. Brieuc Bay. In J. Law (Ed.), *Power, action, and belief: A new sociology of knowledge?* (pp. 196–223). London, Boston: Routledge & Paul. DOI: *https://doi.org/10.1111/j.1467-954X.1984.tb00113.x*

Chazdon, R. L., Brancalion, P. H., Laestadius, L., Bennett-Curry, A., Buckingham, K., Kumar, C., Moll-Rocek, J., Vieira, I. C. G., & **Wilson, S. J.** (2016). When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration, *Ambio*, *45*(5), 538–550. DOI: *https://doi.org/10.1007/s13280-016-0772-y*

Dalby, S. (2020). Bordering sustainability in the Anthropocene. *Territory, Politics, Governance*, *8*, 144–160. DOI: *https://doi.org/10.1080/21622671.2018.1559758*

Damm, A., Paul-Limoges, E., Kükenbrink, D., Bachofen, C., & **Morsdorf, F.** (2020). Remote sensing of forest gas exchange: Considerations derived from a tomographic perspective. *Global Change Biol*, *26*, 2717–2727. DOI: *https://doi.org/10.1111/gcb.15007*

Deleuze, G., & **Guattari, F.** (1987). *A Thousand Plateaus: Capitalism and Schizophrenia*. Minneapolis, MN: University of Minnesota Press.

Descola, P. (2005). *Par-delà nature et culture*. Paris: Gallimard.

Elden, S. (2005). Missing the point: globalization, deterritorialization and the space of the world. *Transactions of the Institute of British Geographers*, *30*(1), 8–19. DOI: *https://doi.org/10.1111/j.1475-5661.2005.00148.x*

Elden, S. (2010). Land, Terrain, Territory. *Progress in Human Geography*, *34*(6), 799–817. DOI: *https://doi.org/10.1177/0309132510362603*

Elden, S. (2013). Secure the volume: vertical geopolitics and the depth of power. *Political Geography*, *34*, 35–51. DOI: *https://doi.org/10.1016/j.polgeo.2012.12.009*

Elden, S. (2017). Legal terrain—the political materiality of territory. *London Review of International Law*, *5*(2), 199–224. DOI: *https://doi.org/10.1093/lril/lrx008*

Fahlbusch, C. (2016, November). Rétrospective et bilan des "pères" d'e-geo.ch, e-geo.ch. *Newsletter*, *28*, 7–8. Retrieved from *www.geo.admin.ch/*

Fässler, D. (2020, June). *Sicherstellung der nachhaltigen Pflege und Nutzung des Waldes. Motion* 20.3745. Retrieved from *https://www.parlament.ch/*

ForêtSuisse. (2020). *Rapport annuel 2019*. Solothurn: ForêtSuisse.

Friedlingstein, P. M., Allen, J. G., Canadell, G. P., Peters, P., & **Seneviratne, S. I.** (2019). Comment on "The global tree restoration potential". *Science*, *366*, eaay8060. DOI: *https://doi.org/10.1126/science.aay8060*

Gabrys, J. (2016). *Program Earth: Environmental Sensing Technology and the Making of a Computational Planet*. Minneapolis: University of Minnesota Press. DOI: *https://doi.org/10.5749/minnesota/9780816693122.001.0001*

Gabrys, J. (2020). Smart forests and data practices: From the Internet of Trees to planetary governance. *Big Data & Society*, *1*, 1–10. DOI: *https://doi.org/10.1177/2053951720904871*

Gartmeier, M., Bauer, J., Gruber, H., & **Heid, H.** (2008). Negative Knowledge Understanding Professional Learning and Expertise. *Vocations and Learning*, *1*(2), 87–103. DOI: *https://doi.org/10.1007/s12186-008-9006-1*

Ginzler, C., & **Hobi, M. L.** (2015). Countrywide stereo-image matching for updating digital surface models in the framework of the Swiss National Forest Inventory. *Remote Sensing*, *7*(4), 4343–4370. DOI: *https://doi.org/10.3390/rs70404343*

Glasersfeld, E. (1991). A Constructivist's View of Learning and Teaching. In R. Duit, F. Goldberg & H. Niedderer (Eds.), *Research in physics 135 learning: Theoretical issues and empirical studies. Proceedings of an international workshop* (pp. 29–39). Kiel, Germany.

Godrillo, G. (2018). Terrain as insurgent weapon: An affective geometry of warfare in the mountains of Afghanistan. *Political Geography, 64*, 53–62. DOI: *https://doi.org/10.1016/j.polgeo.2018.03.001*

Goldstein, J. E. (2020). The Volumetric Political Forest: Territory, Satellite Fire Mapping, and Indonesia's Burning Peatland. *Antipode, 52*(4), 1060–1082. DOI: *https://doi.org/10.1111/anti.12576*

Gollut, C., & **Rosset, C.** (2018). *État de la planification forestière dans les cantons en 2017. Rapport Final*. Bern: FOEN.

Kaul, C. (2019, April). 10 Years of "Law on Geoinformation" in Switzerland - Current Situation and Outlook, 9938. *Paper presented at FIG-Working Week*, Hanoi, Vietnam.

Klauser, F. (2021). Police Drones and the Air: Towards a Volumetric Geopolitics of Security. *Political Science Review*, *27*(1), 158–169. DOI: *https://doi.org/10.1111/spsr.12431*

Küchli, C., & **Blaser, J.** (2005). Forests and decentralization in Switzerland: A Sampling. In C. J. P. Colfer & D. Capistrano (Eds.), *The Politics of Decentralization: Forests, Power and People* (pp. 152–165). London: Earthscan.

Küchli, C., & **Blaser, J.** (2011). Schweizer Waldpolitik – zwischen internationaler verantwortung und nationalen interessen (essay). *Schweiz Z Forstwes*, *162*(4), 96–106. DOI: *https://doi.org/10.3188/szf.2011.0096*

Latour, B. (2005). *Reassembling the social*. Oxford: Oxford University Press.

Latour, B. (2014). The More Manipulations, the Better. In C. Coopmans, J. Vertesi, M. Lynch & S. Woolgar (Eds.), *Representation in Scientific Practice Revisited* (pp. 347–350). Cambridge: MIT Press. DOI: *https://doi.org/10.7551/mitpress/9780262525381.003.0022*

Latour, B. (2017). Visualisation and cognition: Drawing things together. *Philosophical Literary Journal Logos*, *27*(2), 95–156. DOI: *https://doi.org/10.22394/0869-5377-2017-2-95-151*

Law, J., & **Mol, A.** (2001). Situating technoscience: an inquiry into spatialities. *Environment and Planning D: Society and Space*, *19*, 609–621. DOI: *https://doi.org/10.1068/d243t*

Lieberherr, E., & **Thomann, E.** (2020). Linking throughput and output legitimacy in Swiss forest policy implementation. *Policy Sciences*, *53*, 495–533. DOI: *https://doi.org/10.1007/s11077-020-09374-3*

Märki, F. (2020). *Application of ground penetrating radar to study the tree root system architecture in Swiss agroforestry systems* (Master Thesis, ETH, Zurich).

Matthewman, S. (2013). Michel Foucault, Technology, and Actor-Network Theory. *Techné: Research in Philosophy and Technology*, *17*(2), 274–292. DOI: *https://doi.org/10.5840/techne201311205*

McNeill, D. (2019). Volumetric urbanism: the production and extraction of Singaporean territory. *Environment and Planning A*, *51*(4), 849–868. DOI: *https://doi.org/10.1177/0308518X19830699*

Menkman, R. (2019). Refuse to Let the Syntaxes of (a) History Direct Our Futures. In D. Rubinstein (Ed.), *Fragmentation of the Photographic Image in the Digital Age* (pp. 116–128). London: Routledge. DOI: *https://doi.org/10.4324/9781351027946-9*

Mennicken, A. M., & **Espeland, W.** (2019). What's new with numbers? Sociological approaches to the study of quantification. *Annual Review of Sociology*, *45*, 223–245. DOI: *https://doi.org/10.1146/annurev-soc-073117-041343*

Monnet, J. M., Mermin, E., & **Dupire, S.** (2016). Mise en valeur des données LiDAR – Canton du Valais. Rapport Final. *Irstea*., 1–27.

Moser, I. (2008). Making Alzheimer's disease matter: Enacting, interfering and doing politics of nature. *Geoforum, 39*(1), 98–110. DOI: *https://doi.org/10.1016/j.geoforum.2006.12.007*

Noucher, M. (2009). *La donnée géographique aux frontières des organisations: approche socio-cognitive et systémique de son appropriation* (Doctoral Thesis, EPFL, Lausanne). DOI: *https://doi.org/10.4000/cdg.2203*

November, V., Camacho-Hübner, E., & **Latour, B.** (2010). Entering a risky territory: space in the age of digital navigation. *Environment and Planning D: Society and Space, 28*, 581–599. DOI: *https://doi.org/10.1068/d10409*

Olbrich, W. (2019). Technological Expectations and Global Politics: Three Waves of Enthusiasm in Non-Governmental Remote Sensing. *Space Policy, 47*, 107–116. DOI: *https://doi.org/10.1016/j.spacepol.2018.08.003*

Oliver, M. (2014). To be Human is to Sing your own Song. In M. Oliver, (ed.) *Blue Horses* (p. 37). New York: Penguin Press.

Ortloff, W. (1999). Sustainability issues in Switzerland's forests. *New Forests*, *18*(59), 419–433. DOI: *https://doi.org/10.1007/978-94-017-2689-4_27*

Parkan, M. J. (2017) Données LiDAR aériennes: pertinence de l'interprétation visuelle pour la foresterie. *Schweiz Z Forstwes*, *168*(3), 127–133. DOI: *https://doi.org/10.3188/szf.2017.0127*

Parkan, M. J. (2019). *Combined Use of Airborne Laser Scanning and Hyperspectral Imaging for Forest Inventories* (Doctoral Thesis, EPFL, Lausanne). DOI: *https://doi.org/10.5075/epfl-thesis-9033*

Parks, L. (2005). *Cultures in Orbit: Satellites and the Televisual*. Durham: Duke University Press. DOI: *https://doi.org/10.2307/j.ctv11hpmm4*

Pickles, B. J., & **Simard, S. W.** (2017). Mycorrhizal networks and forest resilience to drought. In N. C. Johnson, C. Gehring, & J. Jansa (Eds.), *Mycorrhizal Mediation of Soil - Fertility, Structure, and Carbon Storage* (pp. 319–339). Elsevier, Amsterdam. DOI: *https://doi.org/10.1016/B978-0-12-804312-7.00018-8*

Rath, L., Hilfiker, K., Tinner, R., Ackermann, N., & **Böhler, J.** (2021). Wissenstransfer: *Erkennen der Vitalität von Bäumen anhand von Satellitendaten Abschlussbericht SBB Pilot "Forest & Remote Sensing*". Bern: FOEN.

Rey, L. (2014, February 12). Des prestations qui ont un coût. Comment les garantir à long terme, Dossier Forêt. *Environnement Magazine*, *1*, 12–14. Retrieved from *https://issuu.com/bundesamt-fuer-umwelt-bafu/docs/notre_foret*

Rigling, A., Landolt, D., & **Manser, R.** (2015). The Forest in the Process of Change. In A. Rigling & H. P. Schaffer (Eds.), *Forest Report 2015. Condition and Use of Swiss Forest* (pp. 9–24). Bern: FOEN.

Robbins, P. (2001). Fixed categories in a portable landscape: The causes and consequences of land cover classification. *Environment and Planning A, 33*(1), 161–179. DOI: *https://doi.org/10.1068/a3379*

Rothe, D. (2017). Seeing like a satellite: Remote sensing and the ontological politics of environmental security. *Security Dialogue, 48*(4), 334–353. DOI: *https://doi.org/10.1177/0967010617709399*

Rothe, D., & **Schim, D.** (2018). Sensing the ground: On the global politics of satellite-based activism. *Review of International Studies*, 44(3), 414–437. DOI: *https://doi.org/10.1017/S0260210517000602*
Ruth, A. (2013). Nutzung des Untergrunds: Referate eines Workshops. *Geomatik Schweiz*, *111*(11), 608–622. DOI: *https://doi.org/10.5169/seals-349313*
Rutishauser, T. (Ed.) (2021). Digitalization and change in the forest. *Schweizerische Zeitschrift Forstwesen*, *174*(4), 198–245.
Sassen, S. (2013). When Territory Deborders Territoriality. *Territory, Politics, Governance, 1*(1), 21–45. DOI: *https://doi.org/10.1080/21622671.2013.769895*
Sawyer, S., Erickson, I., & **Jarrahi, M.H.** (2019). Infrastructural competence. In D. Ribes & J. Vertesi (Eds.), *Digital STS hand-book* (pp. 267–279). Princeton, NJ: Princeton University Press. DOI: *https://doi.org/10.1515/9780691190600-020*
Schim, D. (2014). Remote sensing place: Satellite images as visual spatial imaginaries. *Geoforum, 51*, 152–160. DOI: *https://doi.org/10.1016/j.geoforum.2013.11.002*
Schlaepfer, R. (1985). Les inventaires forestiers en Suisse. *Rev. For. Fr.*, *4*, 251–261. DOI: *https://doi.org/10.4267/2042/21807*
Scott, J. C. (1998). *Seeing Like a State*. New Haven: Yale University Press. DOI: *https://doi.org/10.12987/9780300128789-003*
Tordjman, H. (2021). *La croissance verte contre la nature. Critique de l'écologie marchande*. Paris: La Découverte. DOI: *https://doi.org/10.3917/dec.tordj.2021.01*
Tsing, A. L. (2012), On nonscalability: the living world is not amenable to precision-nested scales. *Common Knowledge*, *18*(3), 505–524. DOI: *https://doi.org/10.1215/0961754X-1630424*
Vandergeest, P., & **Peluso, N. L.** (2015). Political forests. In R. L. Bryant (Ed.), *The International Handbook of Political Ecology* (pp. 162–175). Cheltenham: Edward Elgar. DOI: *https://doi.org/10.4337/9780857936172.00020*
Vertesi, J. (2014). Drawing as: Distinctions and Disambiguation in Digital Images of Mars. In C. Coopmans, J. Vertesi, M. Lynch & S. Woolgar (Eds.), *Representation in Scientific Practice Revisited* (pp. 15–35). Cambridge: MIT Press. DOI: *https://doi.org/10.7551/mitpress/9780262525381.003.0002*
Vidalou, J.-P. (2017). *Être forêts. Habiter des territoires en lutte*. Paris: Zones.
Walker, D., & **Artho, J.** (2018). *Les propriétaires forestiers en Suisse. Étude sur les relations des propriétaires publics et privés avec leur forêt*. Bern: FOEN.
Walser, O., Thévoz, L., Joerin, F., Schuler, M., Joost, S., Debarbieux, B., & **Dao, H.** (Eds.) (2011). *Les SIG au service du développement territorial*. Lausanne: Presses Polytechniques et universitaires romandes.
Zürcher-Gasser, N., Kühne, K., Thormann, J.-J., Küffer, C., Schwitter, R., Zürcher, S., & **Frehner, M.** (2016). Échange de connaissances et controlling: les facteurs clés d'une gestion forestière adaptative. In A. R. Pluess, S. Augustin & P. Brang (Eds.), *Forêts et changements climatiques. Éléments pour des stratégies d'adaptation* (pp. 413–424). Bern: Haupt Verlag.

TO CITE THIS ARTICLE:
Dettwiler, D. (2022). Pixelating Forests: Remote Sensing Technologies in Forest Monitoring in Switzerland. *Swiss Yearbook of Administrative Sciences*, 13(1), pp. 1–14. DOI: *https://doi.org/10.5334/ssas.161*

Submitted: 15 August 2021
Accepted: 12 October 2021
Published: 14 February 2022

Swiss Yearbook of Administrative Sciences is a peer-reviewed open access journal published by Ubiquity Press.