Toward a Collaborative Framework: Integrating Remote Sensing Research with Forestry Practice

Lars T. Waser [1*], Nataliia Rehush [1], Hannes Horneber [2], Raffael Bienz [3], Krzysztof Stereńczak [4], Mirela Beloiu Schwenke [5]

[1] Swiss Federal Institute for Forest, Snow and Landscape Research, WSL, Zürcherstrasse 111, Birmensdorf, 8903, Switzerland - *lars.waser@wsl.ch (corresponding author), nataliia.rehush@wsl.ch
[2] School of Agriculture and Food Sciences, HAFL, Länggasse 85, Zollikofen, 3052, Switzerland - hannes.horneber@bfh.ch
[3] Forest Department of the Canton Aargau, BVU, Entfelderstrasse 22, Aarau, 5001, Switzerland - raffael.bienz@ag.ch
[4] Forest Research Institute, IBL, Braci Leśnej 3 Street, Sękocin Stary, 05-090, Raszyn, Poland - K.Sterenczak@ibles.waw.pl
[5] Federal Institute of Technology, ETH, Universitätsstrasse 16, Zurich, 8092, Switzerland - mirela.beloiu@usys.ethz.ch

Keywords: Outreach, Stakeholder, Remote Sensing, Forest Products, Bridging Research and Practice.

Abstract

There is an increasing demand for current and comprehensive forest information due to climate change, economic pressures, and sustainable forest management. Current remote sensing technologies and methodological advances in deep learning provide valuable information for forest assessments, but their integration into forestry practices is slow and user expectations are often unmet due to knowledge gaps and misunderstandings. Challenges include technical language and skill barriers, misunderstanding the information content of remote sensing-based forest products, and adapting existing user processes and systems. Thus, efforts, such as expert groups of researchers and practitioners, aiming to bridge this gap by fostering collaboration, are highly needed. These initiatives should focus on a regular knowledge exchange and active participation of practitioners, needs-orientated practical workshops, and iterative development of remote sensing-based forest products incorporating user feedback. Here, using an example of a first initiative on integrating remote sensing research with practice in Switzerland, we show that collaborative efforts improve remote sensing-based forest products and further stimulate the development of user-orientated methods in the forestry sector.

1. Background and Current State

There is a growing demand in both research and practical applications for cost-effective, accurate, up-to-date and consistently available data (maps) on key forest characteristics, such as tree species composition, wood volume, disturbances, and tree mortality. This demand spans from individual trees and forest stands to the entire country and is driven by the need to optimize forest management, recognize forests as multifunctional ecosystems, and address their vulnerability to climate change, along with economic and social challenges.

Foresters often face challenges due to the shortage of high-quality, up-to-date, and error-free information on forest conditions (Luoma et al., 2017). In recent decades, this gap has been partly closed by employing cutting-edge remote sensing, geoinformation techniques, and artificial intelligence (AI) methods. The growth in the availability of datasets with high spatial and temporal resolution, coupled with advances in machine learning and rapid data processing, has facilitated the creation of reliable, reproducible, and comprehensive forest products (e.g., Waser et al. 2021). These remote sensing-based forest products have the potential to serve as a basis for assessing the current state of forest ecosystems and their future trajectories, while also enhancing existing forest inventory estimates by offering spatially explicit information.

Although these data sets have significant value for forest services and sustainable, multifunctional, and climate-adaptive forest management, their potential is currently only partially utilized. After 40 years of developing remote sensing-based forest products, we identify three issues: 1) their adoption by forest professionals is still reluctant, 2) their correct, intended use is not always ensured, and 3) products fall short of user expectations regarding the content of information, precision and regular updates.

Clearly, there is a question of a mismatch between the progression of remote sensing-based forest products and the needs of their potential users. A common scenario involves the inability to incorporate these products into existing user processes and systems or, conversely, modifying the products to fit these processes. Conversely, creating a remote sensing-based product that perfectly aligns with the needs of practitioners is not always feasible. For instance, maps of tree species derived from airborne or spaceborne data are effective for evaluating the composition of the upper canopy layer but may not accurately represent tree species in the lower canopy. Nevertheless, practical forest assessments generally depend on the entire tree species composition of a forest stand, not just the upper canopy. Therefore, practitioners should also endeavor to comprehend the limitations of remote sensing-based forest products and integrate them appropriately within their systems.

The primary reason for this gap is insufficient communication and collaboration between the scientific community and stakeholders, including forest industries, service providers, forestry professionals and practitioners, and owners who are the ultimate end-users. A longstanding issue has been the limited understanding of the expectations that forestry practice in the local area has of remote sensing-based products. Recently, efforts have been made to address these challenges through stakeholder surveys (see, e.g., Barrett et al. 2016, Fassnacht et al., 2024). The information collected on stakeholders' needs is undoubtedly valuable as it reveals their interest and understanding of the topic and their willingness to use it.

More actions are needed to incorporate stakeholders' needs more effectively in the creation of remote sensing-based data sets. Among many other initiatives on national and European level, a mentionable effort at the European level is the SWIFTT project (SWIFTT, 2025), launched by the European Union and the European Union Agency for the Space Program (EUSPA). This

project aligns with the EU Forest Strategy to improve the protection, restoration, and resilience of European forests by helping foresters manage their forests more efficiently with cost-effective, straightforward, and powerful remote sensing tools.
The expectations of remote sensing-based forest products, such as canopy heights and density, tree species composition, and disturbance maps, are quite high: They are expected to complement or possibly replace traditional methods to detail forest parameters while also serving as input data for specific decision-making processes. This presents a variety of challenges as the properties of remote sensing metrics differ from those acquired by traditional methods. Tackling these challenges needs a shift in both perspective and methodology.
Remote sensing data does not always provide a better description of specific forest traits compared to what foresters have provided using ground-based techniques (such as forest age, forest regeneration, and species composition). Converting the decision-making process to a digital format proves to be time consuming, expensive and complex, when modifying the nature and scope of forest measurements with remote sensing data.
Furthermore, the quality of data is frequently mentioned as an obstacle to the adoption of remote sensing-based data products. Although the concept of data quality is somewhat ambiguous, it typically refers to how accurately and precisely remotely sensed data can depict estimates of the desired forest parameters. In certain instances, remotely sensed data might be considered an inadequately accurate source due to the reported error exceeding a specific threshold or tolerance. However, sometimes discontent with quality arises from misunderstood expectations or incorrect application and analysis of the data, limiting the potential of datasets when they are used properly.
Here, we focus on issues that, once tackled and implemented, will contribute to bridging the divide between research and forest practice in an engaging and sustainable way. First, we explore the core challenges and ways to overcome them to improve the acceptance, appropriateness, and utilisation of remote sensing-based forest products. Specifically, we investigate the causes behind the restricted and inaccurate use of these products. Second, we present a collaborative framework that emphasizes active cooperation between remote sensing researchers and forest practitioners. We use the example of Switzerland's freely available national Forest Type NFI dataset (broadleaf and conifers) (Waser et al., 2021; 2025) to demonstrate the points discussed in our study.

2. Discrepancy Between Remote Sensing Studies and Forestry Practice

2.1 Different Expectations and Goals

Within remote sensing and beyond, researchers are motivated by their internal drive and aim to create innovative approaches that contribute to existing understanding. Their achievements rely on citations, specifically their h-index, publication in highly ranked journals, and the security of funding for ongoing research. Additionally, incentive frameworks for applied research are frequently lacking. Researchers frequently find limited “pots” to access for conducting applied studies and stakeholders frequently have insufficient resources to transform new ideas into practice. Collaboration among multiple stakeholders often falters due to conflicting interests, legislative mandates, or processes.
On the contrary, practitioners are target-oriented and seek measurable improvements from new developments to enhance current processes and products in a user-friendly manner. Frequently, both time and budget are insufficient for conducting extensive experimental projects or thoroughly investigating the theoretical implications and possibilities of new methods.
These differing perspectives do not completely obstruct, but often hinder, effective communication and collaboration between the scientific community and stakeholders. Consequently, this lack of knowledge exchange results in varying expectations regarding these remote sensing-based forest products and confusion about their intended information content.
Although data sets such as canopy height models are effectively used, employing more complex products such as tree species composition, disturbances, or change detection maps is still difficult and can result in misunderstandings and improper use. This results primarily from the differing viewpoints in forest characterization and description—foresters assess from ground level while remote sensing provides an aerial perspective—or the varying levels of experience foresters have with contemporary remote sensing techniques. Furthermore, there are differences between the potential of remote sensing-based methods and products designed in local, smaller, and often simplified case studies compared to their use in individual, often more complex, and larger-scale real-world settings. An important reason is that emerging technologies are primarily implemented in case studies due to the lack of data for larger regions. As a result, these small-scale studies frequently stay at the stage of proof of concept.

2.2 Misleading Illustrations / Product Information Content

Misunderstandings in utilizing remote sensing-based forest products frequently arise from the way information is presented visually. Maps frequently illustrate the top canopy layer but fail to communicate their intended message clearly, which leads to misunderstandings, particularly by those who are not familiar in the data processing techniques used to create these products. For instance, difference or change maps generated by subtracting two datasets (before and after an event) frequently do not provide intuitive indicators to assist in understanding the extent or importance of changes. Additionally, the choice of colors can inadvertently mislead, as users might naturally perceive green as indicating improvement and red as suggesting deterioration, even if these interpretations are not explicitly stated (Figure 1).

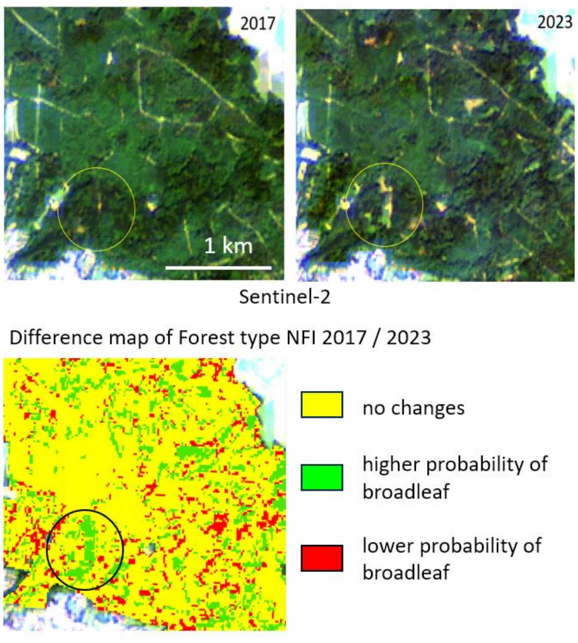

Figure 1. The map illustrates the probability shifts between 2017 and 2023 for the broadleaf class using Sentinel-2 imagery,

highlighting unchanged areas (yellow), decreased probabilities (red) and increased probabilities (green). Significant alterations are observed in the circled area, where conifers have been replaced by young broadleaf (forest management after disturbances), resulting in increased probabilities. This likelihood is supported by Sentinel-2 imagery. On the contrary, in the red regions, where broadleaf probabilities have been reduced, understanding the map becomes more complex and may lead to misinterpretation. Therefore, providing guidance to the users is advantageous (see Section 3.4). The probability changes in these areas are minimal and insignificant (<1%) and are the result of variations in the probabilities of the two models (2017, 2023). The choice of adequate colors in the difference map Forest type NFI is important for the users.
© Lars Waser, includes modified Copernicus-Sentinel-Data (2015-2023), Swiss NFI.

2.3 Inconsistently Used Terminology

An equally important consideration is that users encounter terms that may lead to varying expectations or be misinterpreted. For example, the term 'tree' is commonly used in remote sensing-based forest products regardless of spatial resolution (Figure 2). This results in the term 'tree' being used in products that do not necessarily convey data on individual tree level or lack a clear forest definition, such as the Copernicus High Resolution Layers Tree Cover Density (Copernicus, 2025). This product uses Sentinel-2 images with a spatial resolution of 10 m, which do not allow for the distinction of individual tree crowns.

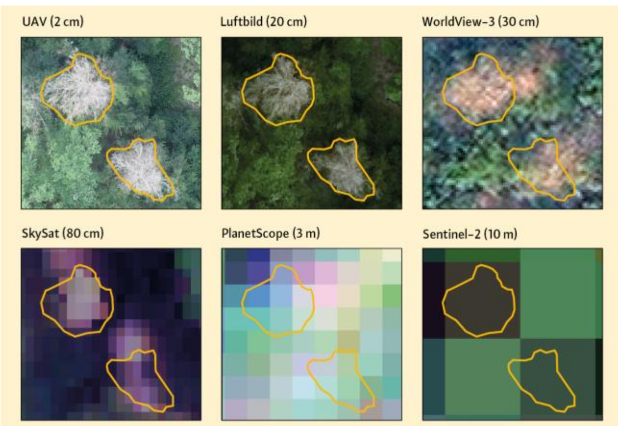

Figure 2. Crowns of individual standing dead trees, as shown in images with different spatial resolutions. Although tree crowns are clearly visible in high-resolution images (top three images), their visibility diminishes in lower spatial resolution images and becomes unidentifiable, such as in Sentinel-2.
© LWF 2025; https://www.lwf.bayern.de/informationstechnologie/fernerkundung/345521/index.php

Furthermore, potential users encounter terms that are outside their expertise or are used inconsistently within the remote sensing community. For example, accuracy measures and statistics related to remote sensing-based forest products are noteworthy, as the choice to use them often relies on the accuracy information provided. The term 'accuracy' with respect to product quality can be vague, but usually refers to the degree of accuracy and precision of estimated forest parameters using remotely sensed data.
It is important to recognize a common misunderstanding regarding the difference between model and prediction (product, map) accuracy/uncertainty. The accuracy of the model refers only to the reference samples (e.g., polygons of the broadleaf and coniferous classes), while the accuracy of the prediction applies to any location on the map and extends beyond those reference samples. Even with nearly identical model accuracies, the resulting products can vary from one to another (see Figures 3, 4). Consequently, the specific intended use and the scale of interest for the map must be carefully considered. Although prediction accuracy may be adequate for applications involving larger spatial extents, where the class proportion per area is sufficient, it may not be suitable for pixel-level analysis in smaller extents, e.g., for forest stands.

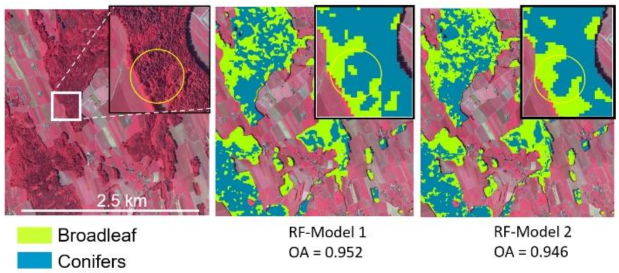

Figure 3. Maps of broadleaf (green) and coniferous (blue) forested areas with the CIR orthoimage in the background for mixed forests in Switzerland. Although two different Random Forest (RF) modeling approaches produce nearly identical overall accuracies (OA), the distribution of broadleaf and conifer pixel varies at the forest stand level (subset box).
© Comprises adapted Copernicus-Sentinel-Data (2021-2023), Swiss NFI and swisstopo.

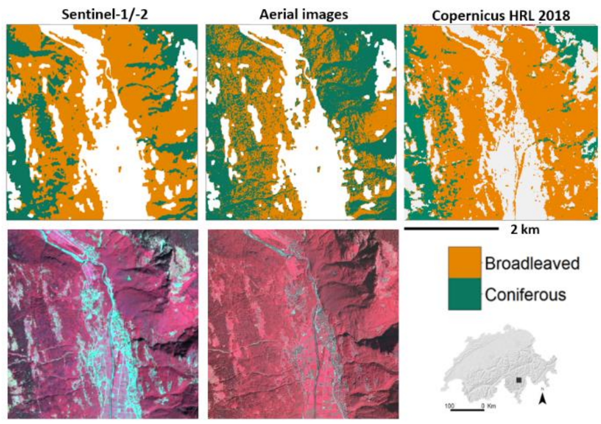

Figure 4. Maps of broadleaf (orange) and coniferous (green) forested areas were derived from three different Random Forest (RF) models from various sources (Sentinel-1/-2, aerial orthoimages, and Sentinel-2 based Copernicus HRL 2018) for a specific area in the southern Swiss Alps. The two CIR orthoimages from Sentinel-2 (left) and an airborne sensor (right) are given for orientation. These maps, which are open access, were used for a variety of applications. While all three RF model accuracies were comparably high (OA ~0.95) across Switzerland, there are notable discrepancies among the three predictions in numerous regions, especially with aerial orthoimages. To interpret and apply the maps accurately, users must rely on the guidance of the map producers, the remote sensing community.
© Comprises adapted Copernicus-Sentinel-Data (2015-2018), Swiss NFI, and swisstopo.

We underscore, that thorough validation of remote sensing-based forest products is essential for their proper application. Model accuracy depends on the split of reference data into training, validation, and testing sets, but product accuracy evaluations require supplementary or independent data. A related issue is that spatial outputs from remotely sensed data might not have been evaluated or validated at a spatial scale pertinent to the end user (Waser et al., 2021; Breidenbach et al., 2022).

3. Toward a Common Pathway

An overview of a common pathway to integrate remote sensing research with forestry practice is given in Figure 5.

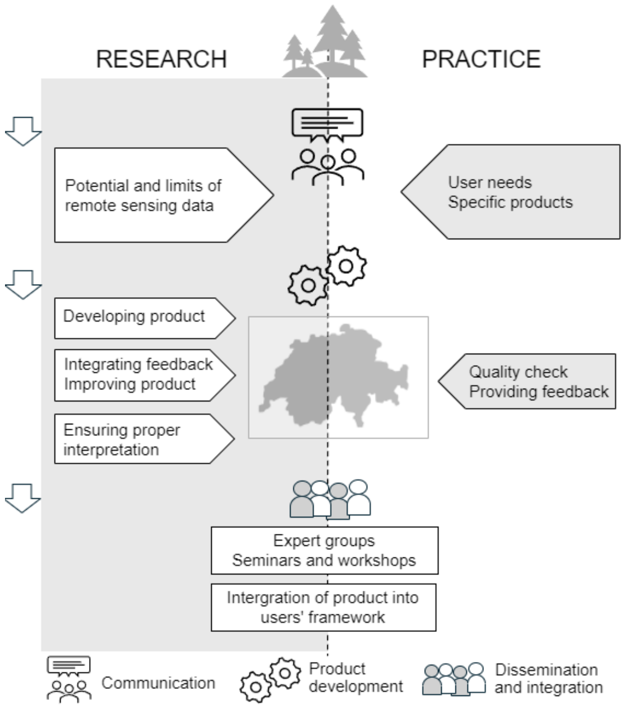

Figure 5. Schematic illustration of a common pathway to integrate remote sensing research with forestry practice summarized by three main steps: 1) communication (sections 3.1 and 3.2), 2) joint product development (section 3.3), and 3) dissemination and integration of the product into users' framework (sections 3.4 and 3.5).

3.1 Collecting Practitioners' Needs and Feedback

3.1.1 Stakeholder Surveys: A systematic and efficient method for gathering information on practitioners' needs is conducting surveys. In the realm of National Forest Inventories (NFIs), Barrett et al. (2016) detailed the findings of a stakeholder survey on the practical application of remote sensing techniques in NFIs in 45 European and non-European nations. While an overall perspective of the employed datasets and methodologies, including pros and cons, is provided, specific user needs, such as accuracy requirements for products, are not included.

However, it is crucial to highlight the integration of detailed operational specifications, such as minimum mapping units, update frequencies, and acceptable uncertainty margins, to adapt remote sensing products to the specific requirements of users. An example of this is the EFINET questionnaire concerning European forest monitoring (EFINET, 2022). It offers a comparative review of current forest information systems, examining their limitations, while also critically evaluating the existing data sources and stakeholder needs, to pinpoint information gaps regarding forests on a European scale. Another remarkable step in this direction was achieved by Fassnacht et al. (2024), who surveyed 355 forest professionals from eight European countries, focusing precisely on the technical needs for four information products derived from remote sensing, covering data on tree species, canopy height, biomass/wood volume, and forest disturbances, and compared them against advances in the remote sensing domain.

Although there is generally high enthusiasm for participation in stakeholder surveys, achieving complete representation remains difficult. The effectiveness of a survey usually depends on various factors, including the clarity of its content, the extent of its dissemination, and the social, educational, political, and regional linguistic backgrounds of its respondents.

Typically, most surveys conducted up to now have been static and singular in nature, frequently lacking systems for ongoing feedback as remote sensing technologies advance. Thus, it would be advantageous for future initiatives to incorporate more interactive and participatory tools and to ensure that the outcomes are consistently integrated into product development processes.

3.1.2 On-site Interviews: The roles of key social participants are influential and reflect the broader social dynamics connected to forests. Generally, a rather limited professional network may result in many stakeholders being acquainted with each other. Consequently, conversations are not only shaped by individual viewpoints, but also by an implicit understanding of the positions, priorities, and sectoral interests of other stakeholders. Familiarity with the context is essential; stakeholders who were already informed about research initiatives participated more actively in discussions, highlighting the advantages of operating within established local networks. Therefore, conducting on-site interviews can be a significant benefit, as they provide the opportunity to observe current power structures within the forestry sector. Professional networks in forest management are deeply interconnected, which means discussions are often guided by both personal insights and shared knowledge. The selection of case studies within a project must proactively address these relational dynamics, as they could greatly affect how forest practices adapt to scientific guidance.

3.2 Exchange Between Research and Practice

Our emphasis is on the interaction between research and practice, although it is noteworthy that cooperation among various stakeholders frequently stalls due to differing interests, regulatory requirements, or procedures. A similar situation is observed within the research realm, where competition and conflicts of interest are prevalent.

3.2.1 The Role of Expert Groups: Expert groups are recognized for their crucial role in connecting two distinct areas of interest, such as research and practice. Ideally, they are made up of an equal number of representatives from both parties, including government agencies, industry partners, and researchers from various institutions. In nations with multiple linguistic areas, such as Switzerland, it is important that each area is included. This not only enhances mutual acceptance but also has a long-term impact on the expert group's productivity.

Regular in-person meetings have proven to enhance effective communication and teamwork, outperforming virtual meetings, which are suggested for brief focused discussions on a particular subject. The core activities involve issuing practical guides, such as a handbook for aerial images interpretation, or for creating digital surface models, or for the verification of remote sensing-derived products. Additionally, by summarizing outreach articles

https://doi.org/10.5194/isprs-archives-XLVIII-M-7-2025-291-2025 | © Author(s) 2025. CC BY 4.0 License.

in specialized journals for practitioners, engaging in and organizing sessions at conferences aimed at outreach, and arranging workshops and seminars on subjects that align with practitioners' needs.

A notable effort in this direction is made by the Forest Remote Sensing Working Group (AFL) (1). This expert group consists of representatives from Austria, Germany and Switzerland and has been focusing on this topic for over 40 years. In Switzerland, in 2022, the Forest Remote Sensing Expert Group (FFF) (2) under the umbrella of the Swiss Forestry Association was founded with representatives from the three language areas.

3.2.2 Events, Seminars, and Workshops: Practice-orientated events, seminars, and workshops on specific topics effectively stimulate the exchange between research and practice. Their success relies on organization, frequency and location, and event structure with the possibility of active participation. These events showcase recent scientific advancements and user applications. Discussions are encouraged and usually occur after presentations, during breaks, and in the plenum. In addition to research updates, networking and social exchanges between colleagues are crucial. While these events are effective in energizing and engaging participants during the event and immediately afterward, this increased motivation and stimulation tend to diminish once participants return to their regular, everyday work routines.

A relatively easy but effective approach to maintaining exchange is by engaging participants in subsequent events. The topics should be determined based on what the participants need. It is essential to gather, address, and rank participants' expectations on specific subjects through surveys or directly during an event. Interactive workshops where attendees learn to apply remote sensing or GIS tools in their routine tasks and how these tools enhance existing methods are crucial. However, this requires a significant amount of time and involves meticulous planning and preparation of data sets, as well as technical support throughout the course. It should be arranged that, if necessary, the educational needs of specific groups are met during the workshops and future sessions.

3.3 Integrating Users in Product Development

User feedback on a forest product is typically restricted and is usually collected only when requested specifically. In such a case, the request for feedback could be part of the agreement to use a data set or available on the website of the corresponding data set. It has been observed that users frequently lack clarity on the type of feedback expected from them and hence, they often refrain from providing any.

This deficiency might be due to the previously mentioned issues, especially the poor interaction between researchers and practitioners, which results in a particular apprehension.

Comprehensive qualitative and quantitative feedback is accumulated on the usefulness and advantages of forest products for a specific user. In particular, in-depth feedback on the accuracy of products across different spatial scales or the spatial units with which the user is engaged holds great value. This process includes extensive quality assessments and comparisons with the user's field evaluations. Preferably, the user provides information on areas identified as incorrect along with any needed adjustments.

The quality of remote sensing-based forest products can be further improved by incorporating additional training data and adjusting model settings and retraining. This process can be done iteratively by gathering new feedback after each phase of the product development (Figure 6).

In these situations, the active involvement of users is beneficial for both sides. First, it aids in the development of an ideal, user-friendly product; second, it collects supplementary reference data. These data are crucial and essential in various ways, particularly for the increasing use of machine learning methods. Consequently, producers are eager to enhance the data set, thus promoting remote sensing research.

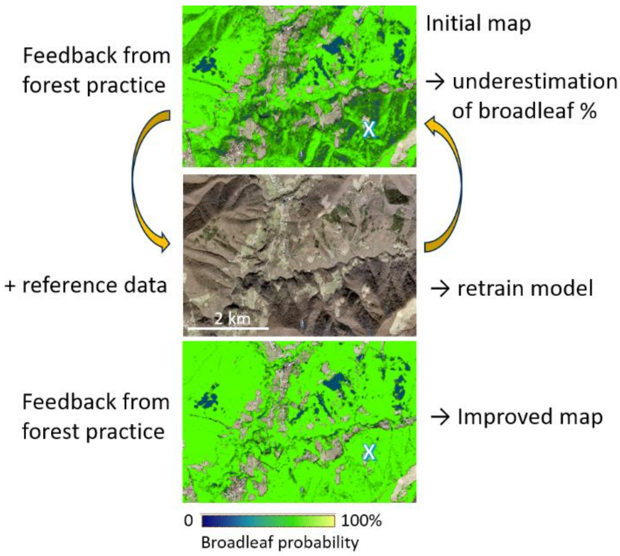

Figure 6. Framework for improving the quality of a remote sensing-based product using the Dominant Leaf Type map for Switzerland as an example. Probability maps of broadleaf (green) and coniferous (blue) areas of mixed forests in southern Switzerland with the leaf-off RGB orthoimage for orientation. Significant differences were evident due to the underestimation of the broadleaf aeas (upper map). With feedback from users (such as forest practitioners) and corrections on misclassified areas, the models underwent iterative retraining and validation. This process generated a final data set that fully meets user expectations. Taking advantage of this insight and the motivating effect of user feedback, examinations of similar areas in the region were conducted, leading to further map enhancements.
© Waser et al. (2025), comprises adapted Copernicus-Sentinel-Data (2021-2023), Swiss NFI.

3.4 Fostering Correct Use of Remote Sensing-based Forest Products

The full potential and value of current remote sensing-based forest products are frequently restricted due to improper use. Various factors contribute to this. Apart from inconsistent and unclear terminology (see Section 2.3), it is crucial to clearly and explicitly convey and explain the specific and intended content to users. This involves providing a coherent and straightforward

[1] Forest Remote Sensing Working Group AFL https://www.waldwissen.net/de/technik-und-planung/waldinventur/fernerkundung-im-forst (in German)

[2] Expert Group Forest Remote Sensing FFF, https://www.planfor.ch/community/section-4/79 (in French / German)

illustration of the forest product (see Section 2.2). Insights from users and our own observations suggest that it is crucial to teach users about precise information content, which can be achieved through workshops and promoting the data set at the time of its release.

Creating impactful maps is advisable and necessitates careful choice of suitable titles, unique legends with precise symbols and scales, and colors that are easily interpretable, emphasize important messages immediately, and are accommodating to color-blind individuals. Furthermore, it is recommended to provide extra documentation to clarify the context, methodologies, assumptions, and constraints.

Moreover, users need more than just one accuracy measure; they also wish to understand how confident the model is in its predictions. To achieve this, we suggest incorporating uncertainty or confidence maps into remote sensing outputs. These maps allow users to carefully assess predictions and make more informed decisions with the extra information provided.

Another useful method, though often less appealing and motivating, is to also communicate what the forest product is not designed for by outlining its limitations (see, e.g., Waser et al., 2021, 2025). For example, the forest type NFI data set (Waser et al., 2025) is not appropriate for analysis at the individual tree crown level because it is derived from Sentinel-2 images with a spatial resolution of 10 m. The provided pixel-level probabilities do not correspond to individual trees. Analysis is recommended only for areas larger than 3x3 pixels, that is, by calculating mean values, except in rare cases of homogenous forest stands (either broadleaf or coniferous). This important information is available in the general description of the data set on the website, as well as when the data set is downloaded. Example illustrations of the data set are also beneficial. Drawing from both our experience and the insights of expert groups, it is common for forestry professionals to overlook the scientific publication associated with the dataset, which contains detailed explanations of its development, validation, and best use practices.

3.5 Promotion of Applied Research

In addition to creating new technologies, more emphasis should be placed on promoting applied research that prioritizes product outcomes for users. As the financial resources typically conclude with the article's publication, covering its release within the project, different means are required to promote financial incentives for practical research. Stakeholders are unable to allocate funds for research due to their focus on product outcomes, resulting in a lack of accountability. We advocate for a more assertive strategy concerning political representatives and contributors. We recognize significant potential in engineering companies and start-ups, which could act as key stakeholders by converting research findings into tangible products for the forestry practice.

The School of Agricultural, Forest and Food Sciences (HAFL) in Switzerland has taken notable steps in this domain by engaging in prototyping and joint development with professionals. Of particular interest is the Toolkit Forest Stand Map (TBk) (3), a straightforward Python algorithm designed to generate a tree stand map utilizing a vegetation height model, developed in close collaboration with practitioners or "end-users".

4. Summary and Conclusions

As mentioned here, remote sensing has become a ubiquitous technology in the scientific domain of forestry, proving its value in aiding monitoring, and mapping activities from individual tree level to national scales. Furthermore, remote sensing-based forest products and tools enable quick evaluation of forest conditions, delivering essential insights into the optimal allocation of resources in response to forest disturbances.

However, the adoption of remote sensing in forest management and monitoring continues to differ significantly between different regions and various applications. Despite certain exceptions mentioned, the frequent use of remote sensing-based forest products is generally limited, even though appropriate technological solutions are available, and datasets are becoming more accessible. This is attributed to insufficient communication and collaboration between remote sensing experts, forest scientists, stakeholders from the forest industry, and regulators.

This paper highlights significant challenges and opportunities related to the integration of remote sensing research into forestry practice and provides potential solutions and strategies to address and leverage these issues in the future. Our aim was not to offer solutions for every possible challenge, but to emphasize key factors that, if tackled or progressed, will improve the utilization and acceptance of remotely sensed products in forestry practice. The expansion of those depends on the interaction of the five key components:

1) To gain a comprehensive understanding of user needs, it is essential to **strengthen exchange** between remote sensing researchers and stakeholders in forestry practice, including those in industry and government roles. This encourages cooperation and engages users in creating forest products, with their achievements driving this comprehensive process. Additionally, it promotes the advancement of remote sensing technologies.
2) **Additional initiatives** on applied research, engineering firms and start-ups can serve as valuable stakeholders by translating research discoveries into practical products.
3) Adjusting methods and products to reflect **"real-world scenarios" ("use cases")** rather than focusing solely on scientific case studies. The methodological advancement of forest products should be aligned with the needs of the end user, encompassing aspects like information content, product accuracy, spatial scale (level of interest) and compatibility with the user's existing data. Another important step is to ensure access to more extensive data for larger regions.
4) **Integrating user needs** into products involves quality check and validation, proper application, and feedback cycles with room for adjustments.
5) Fostering clear and concise **communication and documentation of remote sensing products**, especially in terms of intended use, appropriate interpretation examples and the accuracy and uncertainty of products.

[3] https://github.com/HAFL-WWI/TBk (in English) and https://www.planfor.ch/tools/9 (in German and French)

The interactions involve mutual exchange and feedback both within the individual component and between different components. They promote increased participation in forest research and support forest strategies and initiatives focused on practical applications, spanning from local efforts to those at the European level.
In summary, we present a cooperative framework designed to enhance the interaction between remote sensing researchers and forest practitioners. This framework has resulted in the formation of a dynamic and expanding network with more countries joining, promoting ongoing knowledge exchange. We demonstrate that meeting the demands of practitioners has improved remote sensing-based forest products and is encouraging the creation of user-focused methods in forestry. This initiative marks a significant move towards collaborative solutions for digitalized, innovative, sustainable and climate-adaptive forest management.

Acknowledgments

We thank the participants in seminars, hands-on workshops and the SmartForest Conference 2025 for their enthusiasm and invaluable input on connecting remote sensing research with practical forestry applications. Special thanks go to Shiila Infriccioli from the Department of Environmental Sciences at ETH Zurich for her insightful contributions on effective interview strategies. In addition, we extend our gratitude to the two anonymous reviewers for their thorough and insightful feedback on the extended abstract.

References

Barrett, F., McRoberts, R.E., Tomppo, E., Cienciala, E., Waser, L.T., 2016. A questionnaire-based review of the operational use of remotely sensed data by national forest inventories. *Remote Sensing of Environment* 174, 279-289. https://doi.org/10.1016/j.rse.2015.08.029

Breidenbach, J., Ellison, D., Petersson, H., Korhonen, K.T., Henttonen, H.M., Wallerman, J., 2022. Harvested area did not increase abruptly—how advancements in satellite-based mapping led to erroneous conclusions. *Annals of Forest Science*. 79, 2. https://doi.org/10.1186/s13595-022-01120-4

The European Forest Information Network, EFINET, 2022. https://efi.int/news/efinet-questionnaire-european-forest-monitoring-2021-12-09

Fassnacht, F.E., Mager, C., Waser, L.T., Kanjir, U., Schäfer, J., Buhvald, A.P., Elham, B., Shafeian, E., Schiefer, F., Stančič, L., Immitzer, M., Dalponte, M., Stereńczak, K., Skudnik, M., 2024. Forest practitioners' requirements for remote sensing-based canopy height, wood-volume, tree species, and disturbance products. *Forestry*. https://doi:10.1093/forestry/cpae021

Luoma, V., Vastaranta, M., Eyvindson, K., Kankare, V., Saarinen, N., Holopainen, M., Hyyppa, J., 2017. Errors in the Short-Term Forest Resource Information Update. In I. Ivan, A. Singleton, J. Horak, & T. Inspektor (Eds.), *The Rise of Big Spatial Data* (pp. 155-166). (Lecture Notes in Geoinformation and Cartography). Springer International Publishing AG. https://doi.org/10.1007/978-3-319-45123-7_12

SWIFTT, 2025. Satellites for Wilderness Inspection and Forest Threat Tracking. European Union, European Union Agency for the Space Programme (EUSPA). https://swiftt.eu/

Waser, L.T., Rüetschi, M., Psomas, A., Small, D., Rehush, N., 2021. Mapping dominant leaf type based on combined Sentinel-1/-2 data – Challenges for mountainous countries. *ISPRS Journal of Photogrammetry and Remote Sensing* 180, 209-226. https://doi:10.1016/j.isprsjprs.2021.08.017

Waser, L.T., Ginzler, C., Psomas, A., Rüetschi, M., Rehush, N., 2025. Forest Type NFI. *National Forest Inventory (NFI*). doi:10.16904/1000001.7. https://www.envidat.ch/#/metadata/82d763fa-123a-4648-b827-0dec02a5efbc