FOREST MONITORING TO PROMOTE SUSTAINABILITY IN THE 21ST CENTURY

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Forest monitoring programs have to increasingly meet emerging in formation requirements of our changing world. In order for these programs to be useful for sustainability considerations, they should also be based on an appropriate, operational concept of sustainability. However, such a concept and how the sustainability (or unsustainability) of human actions can be indicated are still open issues, and many currently applied indicators are inappropriate measures. The paper outlines a possible definition of sustainability that is based on the quantitative estimation of utilization rates and related environmental capacities. The concept is demonstrated using the example of the global carbon balance and how a sustainable pathway of emission reduction can be indicated. The definition of "forest" also has to be revised by broadening it considerably so that it includes a reference to all products and services that society expects from forests. This, and the fact that the forestry sector has to operate in a globalized world while its effects have also gained global relevance e.g. concerning the global carbon cycle, inevitably require that new information is collected. These include carbon stock changes under the UNFCCC and the Kyoto Protocol that must be reported for six forest carbon pools and many land use and land use change categories. These and other recent new monitoring and reporting requirements have contributed to the rapid improvement of forest inventories, but developing them further is necessary to meet international quality criteria, to only collect useful information, and to ensure that data collection is economically feasible.

Keywords: sustainability, utilization, capacity, forest monitoring, carbon cycle.
Parole chiave: sostenibilità, utilizzazioni, monitoraggio forestale, ciclo del carbonio.

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1. Introduction

Forest monitoring has a rather long history, its origins dating back to the 14-15th century when the focus was on what one might harvest. Not much later, forests were not able to meet the growing demands of mines and industry for timber any more. In order to ensure a sustainable timber supply in the long term, Carlowitz (1713) coined the idea of sustainability, and the technical term ("Nachhaltigkeit") for it. He and his contemporaries had to make sure that, somehow, no more timber is cut than what is produced. This in turn required information on the amount of both the harvests and the increment of forests. Over time, this lead to the repeated assessment, in specific areas, of wood volume or its growth. Although the first yield tables were constructed in 1795 by Paulsen (Pretzsch, 2009), the monitoring of volume and growth for the purpose of the sustained yield concept was not possible for many decades and forest area was sometimes used as a proxy. Nevertheless, the need for data had the important effect that, first in Germany and then elsewhere, dendrometry and forest growth and yield studies went through an enormous development (for details, see Pretzsch, 2009). The concept of sustainability later developed to a standard requirement that is referred to today as the sustained yield concept. Importantly, this is a quantitative concept: "Sustained yield management of wood … would, in technical terms, be considered to be achieved if the total harvest does not exceed the accumulated annual increment during a specified planning period" (FAO, 1998). Using a formula:

$$AAC \leq I_{net} \quad (1)$$

where:
AAC = Annual Allowable Cut (or sustainable annual cut); and
I_{net} = periodic increment of the forests planned during a specific planning (or accounting) period.

This concept, the variations of which have been used in forestry since the 19th century and in fisheries and elsewhere since about a century later, is currently reflected in the strong requirement that the value of standard forestry statistics such as forest area, standing volume, woody increment and forest biomass carbon stocks should grow, or at least are not supposed to decrease (e.g. Somogyi and Zamolodchikov, 2007). The concept was generalized by Daly (1990) who stated that with renewable capacities, harvest rates should equal regeneration rates. The concept has seen a substantial development for the last decades due to the realization that forests do not only provide wood but also a number of other products as well as services. About a quarter of a century ago, after a serious forest decline, public and professional attention in Europe started to focus on these services. Both in Europe (MCPFE, 1993) and elsewhere, so called criteria and indicator systems were set up in an effort to monitor the status of as many such services and products, and/or as many forest characteristics deemed relevant, as possible. In Europe, these efforts lead to the creation of the framework of a national level monitoring system that, after having been modified a few times, currently includes 35 quantitative and 17 non-quantitative indirect country-level indicators (Forest Europe, 2011). This system, just like many other similar systems used elsewhere, is partly an analytical approach in the sense that it focuses on specific quantitative characterristics of a very complex system such as wood growth, but it is partly non-analytical, i.e., it uses quantitative or quailtative information, e.g., whether forest management planning exists in a country, to describe in an integrated way if the system can be sustained. Whether analytical or non-analytical, appropriate indicators need to be systematically measured or estimated, their dynamics need to be assessed, and the result of the assessment need to be used as a feedback if the sustainability of forest management is to be ensured. However, the Forest Europe system is underdeveloped in all of these aspects.

It includes inappropriate indicators, which leads to inconsistencies. For example, the overall assessment based on Part B group of indicators suggests that policies, institutions and instruments (by policy area) are at a good level (with four "trees" on a scale from one to five) for Russia, North Europe and Central-West Europe, and at a medium level (with only three "trees") for Central-East Europe, South-West Europe and South-East Europe, whereas the assessment of Criteria 1: forest resources and global carbon stock only yielded three "trees" for the first group of regions, and four "trees" for the second. Does this really mean that "good" policies, institutions and instruments have in fact adverse effects and need to be changed, or it is the criteria and indicators, as well as their assessment, that need re-thinking? Also, monitoring programs do not sometimes provide the required data or they produce too much data, it applies an oversimplified framework of indicator assessment, or lacks an assessment theory altogether. Finally, the results of the monitoring have rarely used to develop appropriate forest management options. As a recently completed review of the Forest Europe system stated, the entire system is "in need of revision" (EFI, 2013). This system together with other international reporting requirements (see below) are important forces of developing current and future monitoring programs. An important requirement for these programs is that they should promote sustainnability in as many ways as possible. These programs will also have to meet emerging information requirements of our changing world that, at the same time, is becoming increasingly complex. In further developing the current monitoring systems, the three probably most important aspects to consider are: what is "sustainability"? what is "forest"? and: what (which indicators) do we need to monitor?

2. An extended and generalized operational definition of analytical sustainability

Although the concept of "sustained yield" has been used in forestry for centuries, the broader concept of "sustainability" has only a history of a few decades, and it still has its definitional challenges, which makes it difficult to operationalize it in a monitoring program. Both the analytical and the non-analytical approaches have their challenges. Concerning the analytical approach, most currently applied definitions of sustainability are narrative that usually refer to the *intention* or *hope* to maintain, in an undefined manner, extent or way, environmental capacities that have been exploited to meet human needs, also undefined, until an undefined point in future. (For example, sustainable forest management is defined by MCPFE (1993) the following way: "The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national and global levels, and that does not cause damage to other ecosystems."). However, such intentions and hopes can only be fulfilled if relevant levels of environmental variables such as stocks or fluxes are sustained in practice by limiting the utilization of related environmental capacities so that they are not overexploited. This in turn is only possible if quantitative natural laws, including the law of the conservation of mass and energy, are observed. As the current definitions are not directly applicable for modeling the sustainability of complex environmental systems, they have to be replaced by an approach that is generally used in engineering (Somogyi, 2014). Such a possible approach can be the extension and generalization of the sustained yield concept. For any system, the mathematical requirement of the sustainability to maintain a flux (i.e., the use of a capacity) for any relevant period of time is that the sum of the subtraction from a related stock (i.e., the utilization) during the period cannot be larger than the sum of additions to the stock (if possible) and/or the acceptable rate of reduction of the stock (i.e., capacities) during the period:

$$\sum U \leq \sum C \quad (2)$$

where:
U: utilization;
C: capacity;
$C = C_{non\text{-}ren} + C_{ren} + \Delta C$
$C_{non\text{-}ren}$: non-renewable (e.g., volume of a primary forest);
C_{ren}: renewable (e.g., regrowth); and
ΔC = G – L = gains – losses due to non-utilization related events (e.g., afforestations as human-induced enhancement of forest resources, and natural disturbances as a form of natural catastrophies that destroy capacities).

In order to ensure that the calculations, which in practice inevitably involve uncertain estimates, do not lead to high rates of utilizations, margins of safety should be applied to all of the variables. The above also means that sustainability can only be defined for periods of well-defined length (whether *a proiri* or *a posteriori*), however, the above requirements do not guarantee that the flux can be sustained after that period. Therefore, if sustainability is required for a long time, applying the planning or accounting periods referred to in Equation 1 above may not suffice to ensure sustainability for those periods. If sustainability is to achieve in a long term, the periods to which the above requirements should be applied should be *long enough* to match the "long term".

Many indicator systems, including that of the Forest Europe (2011) system, do not consider the above. It is partly for this reason that simple annual statistics or „statistics A / statistics B" (e.g. carbon footprint, many Forest Europe indicators) are poor sustainability indicators. Below is an example of how the above definition might work, and how appropriate indicators could be developed. The example concerns the necessary need to reduce global net emissions in the near future, which includes reducing emissions from global deforestations, maintaining forest carbon stocks and enhancing the forest carbon sink.

The example also demonstrates that such extra-sectorial considerations may also affect how monitoring programs have to be developed. As Earth has one atmosphere, all emission will increase the carbon-dioxide concentration of the air, which leads to global warming. It is estimated that the increase of global mean temperature can only be limited to 2°C, which is necessary to avoid adverse effects for human populations, if the amount of cumulative emissions between 2000-2100 will not exceed about 2650 $GtCO_2eq$ (UNEP 2013; IPCC 2013). Taking into account that the cumulative emissions between 2000 and 2011 amounted to about 500 $GtCO_2eq$, total anthropogenic global emissions between 2012-2100 must be kept below the remaining amount of about 2150 $GtCO_2eq$.

This estimate has a confidence interval of about 1740-2210 $GtCO_2eq$, and applying a margin of safety equal to the half width of this confidence interval, this means that the capacity of the atmosphere to absorb emissions is equal to 1740 $GtCO_2eq$. Mathematically, future emissions must be reduced and then practically eliminated to avoid that total emissions exceed this capacity. Of all the possible emission trajectories that satisfy this requirement, Figure 1 demonstrates one such a trajectory that could be treated as a plan. An indicator that could be used to assess if progress is according to plans could measure how close (or far) cumulative future emissions are relative to the planned pathway. Indicators of similar conceptual basis may be more useful than current ones in ensuring forest sustainability. In order to develop such indicators, specific analyses of sustainability are needed concerning each forest characteristics, or forestry aspect, that may be relevant for the overall sustainability of forests and forest management.

3. The re-definition of forests

The overall sustainability of forests and forest management may largely depend on what we want to use and manage forests for. The list of the important goals, and the associated definition of "forests", have been broadened considerably for the last decades, and includes now a reference to many products and perceived services that society expects from forests. Additionally, many traditional values such as timber, the meat of many wild animals, erosion control and others, have been made to look less valuable than values like tourism (including all of its variants from skiing to mountain biking and eco-tourism), biodiversity, and the role of forests in global cycles such as the global carbon cycle. This does not mean that old values have lost their importance, on the contrary: the need for products such as wood has been constantly increasing. In fact, most income from forest is still from wood production. However, forest managers have had to learn that they have to consider many other issues when managing forests. Of all these issues, one that has gained global importance is the need to preserve carbon stocks of forests and to maintain and enhance the forest carbon sink. About 10% of all anthropogenic emissions, which cause climate change that, arguably, constitutes the biggest challenge to mankind, are due to deforestations and other forest-related emissions (IPCC, 2013). An important related development recently is that land use changes have been diversified as never before (Fig. 2) and accelerated in an attempt to better meet land-related needs such as food, tourism, protection of the environment, water and also forest-related needs. In order to monitor land use related emissions and removals, these land use changes need to be monitored even if, quite often, the number of the land units that are subject to one-time or frequent land use change is large and their size can be quite small, which makes it increasingly difficult to monitor them. In many cases, only modern remote sensing technologies, possibly together with appropriate ground truth, are able to cope with this task, and only in case an integrated (i.e., not land use specific) mapping is done.

In addition to changes in the perception of forest products and services, and the forest area changes due to direct human induced activities, large-scale changes can be expected in forest species composition if climate change will advance as predicted. As a result, species and forest ecosystems may go extinct locally, to be replaced by other species (Zimmermann *et al*., 2013; Móricz *et al*., 2013).

This will require a rather dynamic re-definition of forest composition, too, which is an important aspect of forest monitoring programs.

4. Criteria for monitoring for analytical sustainability

The above inevitably means that, along with some traditionally collected data, new types of information must be monitored in forests. However, forest parameters to monitor should be well selected, which requires a number of criteria. Below is a non-exhaustive list of criteria (that are linked to the requirements in Equation 2) together with examples that are intentionally selected to include parameters outside of the forestry, which is to demonstrate how such external considerations have also been considerably affecting the monitoring programs of the forestry sector. First, a clear idea is needed as to what needs to be sustained. In addition to the list of forest and forest management related issues, relevant parameters related to environmental issues external to the forestry sector should also be considered. These issues include climate (or, more specifically, temperature). In the globalized world of the 21st century, the forestry sector and local enterprises have to be managed not only in a highly competitive economic environment, but also under the provisions of various international agreements such as the Kyoto Protocol (KP). Second, a clear idea is needed as to which variables are direct utilizations of capacities(such as wood harvesting) and which are needed (e.g., greenhouse gas emissions) in case what is to be sustained is not a flux in itself or not linked to utilization. These variables must also be linked to capacities (e.g., tree growth or the absorption capacity of the air) that are also need to be identified and monitored. Third, a clear idea is necessary about the time frame that is need to be identified to ensure sustainability. The identification is system-specific (i.e., no general rules can be set), and may not be equal to planning periods. In the case of the mitigation of climate change, the time frame can only last until we can still avoid adverse effects by considerably reducing global net emissions.

Fourth, clear theories are necessary as to how to evaluate monitoring estimates, i.e., how they ensure the sustainable utilizations of capacities, how this use can be indicated, and what policies and measures are needed to ensure sustainability for the various utilizations. This may require the understanding of complex systems (e.g., the carbon cycle, or the biodiversity of ecosystems). As both forests and their environment are complex, this requirement may pose serious challenges to forest research. Without such theories, however, the risk is not only that inappropriate sustainability policies and measures are developed, but rather that false sense of sustainability might be developed in certain situations that may lead to counter-productive policies or measures, or even ones that may be outright dangerous in the long term. Finally, data collection must be practicable, well planned and cost-effective to avoid the situation, which is currently the case for several indicators, that data is collected but cannot be really used, while other data cannot be properly collected due to economic considerations. Clearly, in order that forest monitoring programs can better be used to ensure sustainability, they may need to be revised both at the country level, and at the level of the Forest Europe system of indicators.

This revision can be based on a thorough analysis to only include indicators that meet the above requirements. Research should be conducted as to how forest changes and health as affected by climate change can be monitored in order that optimal adaptation is possible.

Also, many countries that ratified the UNFCCC and the Kyoto Protocol, including all EU countries, have to collect a large body of information in the Land Use, Land Use Change and Forestry (LULUCF) sector that (beginning the inventory year of 2013) is called the Agriculture, Forestry and Other Land Use sector (IPCC, 2006). Variables to monitor under these regulations are relevant for the global carbon cycle and the UNFCCC. Recent EU provisions (Regulation 525/2013, Decision 529/2013) incorporate these requirements but also extended them. These requirements have already had an enormously positive effect on the development of forest inventories. For example, some countries moved from questionnaires to sample-based inventories, introduced remote sensing and geographical information systems, developed their area inventory, improved their biomass estimation system, and extended data collection to obtain information on previously not monitored carbon pools such as deadwood and soils. However, further efforts are needed to enable all countries to meet all reporting variables at the quality required.

The above reporting requirements are based on the standardized methodology by the IPCC (2006) that include the need to report carbon stock changes for specifically defined land use or land use change sub-categories such as: land converted to forest land (UNFCCC) and afforestations (KP);

a) forest land converted to other land uses (UNFCCC) and deforestations (KP);

b) managed (existing) forests (UNFCCC)and land under “forest management” (FM under the KP; lands to be reported in these categories may have different definitions);

c) land affected by natural disturbances (this is included in all of the above, but can also be separately reported on a voluntary basis under the KP in order to exclude emissions from such disturbances from accounting); and

d) forest land established on former non-forest land to compensate for deforestation in FM land under well-defined conditions (KP).

For each of these land use and land use change types, the IPCC (2006) methodology requires the estimation of carbon stock changes for the following carbon pools: above-ground biomass, below-ground biomass, deadwood, litter, soil and harvested wood products.(In case it can be demonstrated that a pool is not a source, it is not required to report and estimate of the removals.) As former forest monitoring programs (except for ones for scientific goals) focused on traditional forest variables such as area, volume, increment, mortality and harvest, obtaining the necessary information for these pools may require specific efforts, including a better coordination with research programs. As a conclusion, forest monitoring programs have to continuously be revised to better serve their objective to ensure sustainability. More specifically, the scope of the analytical variables to assess have had, and may further have to, be both reduced and broadened to provide all information required but only that, data collection and reporting on estimates needs to meet increasing quality criteria while data collection also has to continue to be economically affordable, and theories need to be developed based on which appropriate sustainability assessments can be done. These theories should also be used to revise the concept of sustainability indication, which may also have an effect of the further development of monitoring programs. Further efforts may also be needed in case non-analytical indicators (e.g., Bastrup-Birk *et al*., 2014) are to be used. In order that such indicators are successful, they need to be able to address questions such as what is "natural"? what and how to monitor? (e.g., bioindicators?) how to assess monitored variables? what does „naturalness" indicate? under what conditions does it also indicate „optimal" level of services and products? how can policies and measures be developed from monitored values? and of course: which indicators, and how, may be appropriate to correctly assess whether sustainable utilization pathways are observed?

Finally, well presented information from recent forest monitoring programs have proved to be useful to both enhance the recognition of forests and the forestry sector and promote sustainability worldwide. Therefore, further efforts may be needed to not only meet official reporting requirements, but rather, to use information collected in monitoring programs and generated during the analysis of estimated data to better inform forest managers at all levels, and also society at large so that appropriate actions can be taken to ensure the sustainability of forests as well as their multiple products and services.

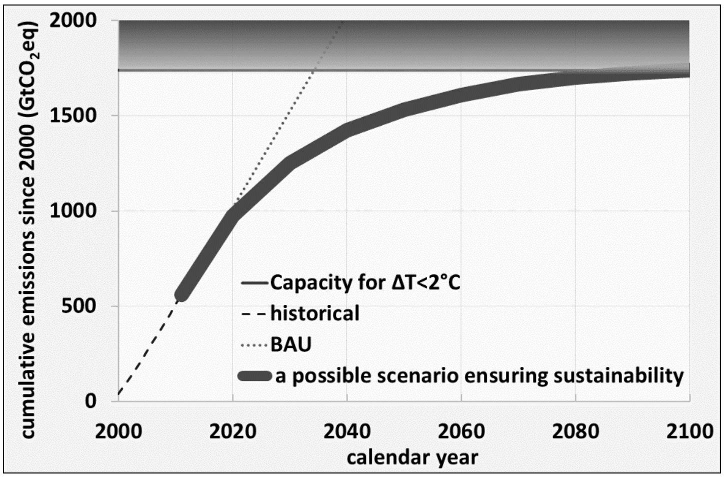

Figure 1. Cumulative emissions as utilization (historical global emissions (dashed line), their linear "business as usual" extrapolation (dotted line) and a possible pathway of cumulative future emissions (thick line), and the capacity of the air to absorb these emissions (which should not be exceeded in order to avoid a temperature increase of more than 2 °C) as a wide range on the top or the chart. The thickness of the curve of the possible pathway and the range indicates the rather high uncertainty of the estimates.

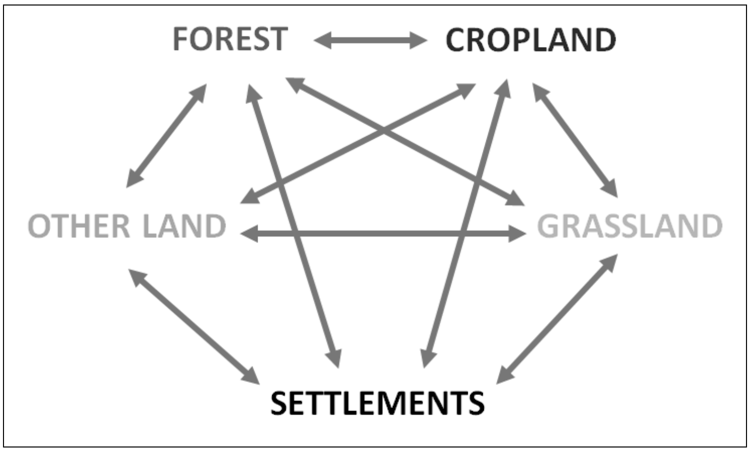

Figure 2. A schematic representation of all possible land use conversions (the broad land use and land use change categories shown in this figure are those of IPCC, 2006).

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