Issues in Accounting for Regulating Ecosystem Services: Baselines and Demand

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1) Introduction

In order to implement physical ecosystem service accounts, each individual ecosystem service flow needs to be assessed using service-specific measurement or modeling approaches. Nevertheless, the System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA EA) framework provides a set of general principles that standardize the way ecosystem service flows are accounted for, such as rules for supply and use tables or definitions of final and intermediate services. Other conceptual and practical issues, although discussed in the general framework, are not addressed in a definitive manner and left open to the compilers. This makes sense, as the implementation should be flexible and tailored to the purpose of each accounting exercise. However, when compilers like national statistical offices produce comprehensive, regular and internationally comparable ecosystem accounts, some general principles should be applied consistently across all services.

In this paper, we identify two conceptual and/or methodological challenges that arise when implementing ecosystem service accounts in the new standardized framework. We argue that compilers of ecosystem accounts for multiple services and multiple ecosystems should carefully implement a standardized approach to deal with the following issues:

- The use and communication of clearly defined and appropriate baselines for regulatory services
- Incorporating ecosystem service demand

2) Baselines for regulatory services

Unlike in the case of provisional services, where the total flow is simply measured as the difference from zero provision, the measurement of regulatory services often involves some counterfactual situation. In fact, SEEA EA states that “it is normal to make an assumption as to what services would be supplied if the ecosystem type or its characteristics were different” (SEEA EA, 2021). It also stands to reason, that these “different” ecosystem types or characteristics would be such that the service flow would be either zero or minimal. Typically, regulating services remediate negative impacts like air pollution, erosion or flooding (see Table 1). Services like soil erosion control or air filtration are therefore linked to a stock or flow that is regulated, in these examples particular matter (PM) or erosion (see Figure 1). The regulated stock or flow observed with the current ecosystem type and characteristics is compared to a baseline level that minimizes the ecosystem service flow. The difference between the two levels then represents the actual ecosystem service flow.

When there is zero baseline ecosystem service flow, the regulated stock/flow is typically non-zero, thus creating a negative impact on society or economy. For example, some erosion takes place regardless of vegetation cover, but the service of “soil loss mitigation by vegetation” on bare land (the baseline) is zero. In another example, when there is no carbon sequestration by forests, the concentration of greenhouse gases is higher. There are arguably other services, where the baseline ecosystem service flow is positive (see Section 2.1). For instance, soil organic carbon emissions (the regulated flow) and the service of “carbon retention” of bare land (the baseline) may both be positive in the short-run.

Table 1: Regulating Services and their baselines according to SEEA EA

Ecosystem service	Baseline SEEA EA, 2021
Global climate regulation	No/zero carbon retention or sequestrations
Local climate regulation	/
Air filtration	No/zero air filtration
Flood mitigation	Bare land
Soil erosion control	Bare land
Water purification	No purification

SEEA EA provides suggestions for meaningful baselines for selected services that broadly follow the logic described above. It is also advices to clearly indicate, motivate and communicate the choice of baseline (United Nations et al. 2021). While we agree with this advice, we believe there are remaining conceptual (Section 2.1) and empirical challenges (Section 2.2) that deserve increased attention. In particular, when ecosystem service accounts are produced in a standardized approach across multiple services and ecosystems and compared across countries, the choice of baselines and their measurement require a common logic as well as a well-defined conceptual and methodological basis.

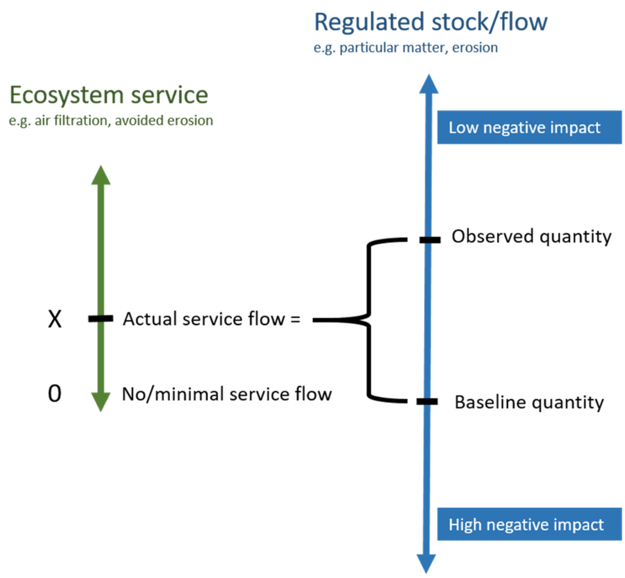

Figure 1: *Regulating ecosystem services (green) directly influence the observed quantity of the regulated stock/flow (blue). The Difference between the observed and baseline quantity equals the actual service flow. Higher actual service flows thus lead to lower negative impacts.*

2.1) Conceptual challenges

Non-zero baseline ecosystem service flows: Conceptually, the choice of baseline is basically a thought experiment: What would happen, if the ecosystem type, for which a service is measured, would change to a different type (or condition). It makes sense that a meaningful counterfactual for a specific service is the hypothetical conversion to that ecosystem type that would minimize the service flow (worst case scenario).

Finding an ecosystem type that minimizes the flow means minimizing the potential for an ecosystem to provide a particular regulatory service (demand in this thought experiment is fixed). This potential is based on:

i) Its type, as recorded in the extent account. Most often, the crucial component is the type of vegetation (sequestration, erosion, air filtration, flood mitigation).

ii) Its condition, as recorded in the condition account. Here multiple components may play a role: the occurrence of organic soil (CO_2 retention), the quality of vegetation (e.g. tree cover density for air filtration), soil characteristics (e.g. drought for water flow regulation) and others.

Baselines are typically linked to extent conversions (different types) rather than changes in condition, mainly because we are interested on the extensive (what if the ecosystem would not exist) rather than the intensive (what if forest would be in worse condition) margin to measure the total flow of a service.

Often, finding an appropriate hypothetical conversion is fairly straightforward, meaning that the baseline makes sense from biophysical perspective and is feasible to measure. For instance, any conversion to a non-vegetated ecosystem type would lead to zero carbon sequestration. Similarly, conversions from vegetated to bare land would minimize the mitigation of soil erosion. Therefore, it does not make sense to choose, for example, bare rocks as the baseline, because a hypothetical conversion is unlikely to happen, even though the baseline quantity would also be minimal.

There are however instances, when the choice is conceptually more difficult and baselines may not represent worst case scenarios. There is no hypothetical conversion that would lead to zero carbon retention (at least in the short run). This is due to the fact that the service is not only dependent on biomass, but is also linked to a specific condition (soil organic carbon content) and is strongly related to land use and management practices. While a sensible worst-case scenario would likely be intensive agricultural use, it makes sense to abstract from use and management and consider conversions to bare land. This reflects the underlying assumptions of the carbon-at-risk concept, where only the fraction of carbon retention linked to ecosystem characteristics is accounted for.

Similarly, in the case of air filtration, there may still occur dry deposition of PM on bare land, depending on the topology of the landscape (ruggedness, surface type), which would mean there is no clear hypothetical conversion that supports a zero provision of the service. Non-zero baseline ecosystem service flows may depend on ecosystem condition and/or additional data on topology, weather and climate.

> *These special cases can potentially be addressed in two ways. First, by linking the service directly to vegetation (carbon retention and air filtration by vegetation) in a strict manner, such that the default baseline bare land does feature in the supply table. Second, by using an exceptional zero baseline that does not reflect a hypothetical conversion. Given that, strictly speaking, the latter is not consistent with most other services, the exception should be clearly marked.*

Multiple baselines: It may be necessary to define different baselines for the same service depending on the ecosystem type because the supplying ecosystem types are vastly different. For instance, carbon sequestration by terrestrial and marine ecosystems functions in different ways. For the ocean, it consists of physical and biological carbon pumps as well as coastal ecosystems like saltmarshes and seagrass beds. A conversion of coastal waters with macrophytes to bare seafloor would reduce the service flow, but some sequestration may still occur. On the other hand, bare land as a baseline for sequestration for forests generates a zero-service flow.

Different baselines for the same service can also be the consequences of methodological choices, i.e. stemming from the method that is used to estimate the baseline. Local climate regulation (urban cooling effect of vegetation) by trees may be estimated for both urban parks and urban trees/alleys. Actual air temperature is compared to a counterfactual prediction under a no-vegetation scenario, which features a mix of bare/grass land and sealed surface baselines (Marando et al., 2022). Figure 2 illustrates this issue using an example from Bonn, Germany. The cooling effect of trees in a park-like area (left) and on a street and parking lot (right) is estimated within the same multiple regression framework. First, the function between temperature and tree cover is estimated. Second, temperature for each pixel is predicted setting tree cover to zero. Third, the difference in observed and predicted temperature is calculated (cooling effect). While the high-resolution data on tree cover and vegetation (Normalized Difference Vegetation Index, NDVI) captures urban green cover well, the surface below remains difficult to identify (and thus goes to the error term of the regression). The model intercept will reflect a mix of green and sealed surface baselines.

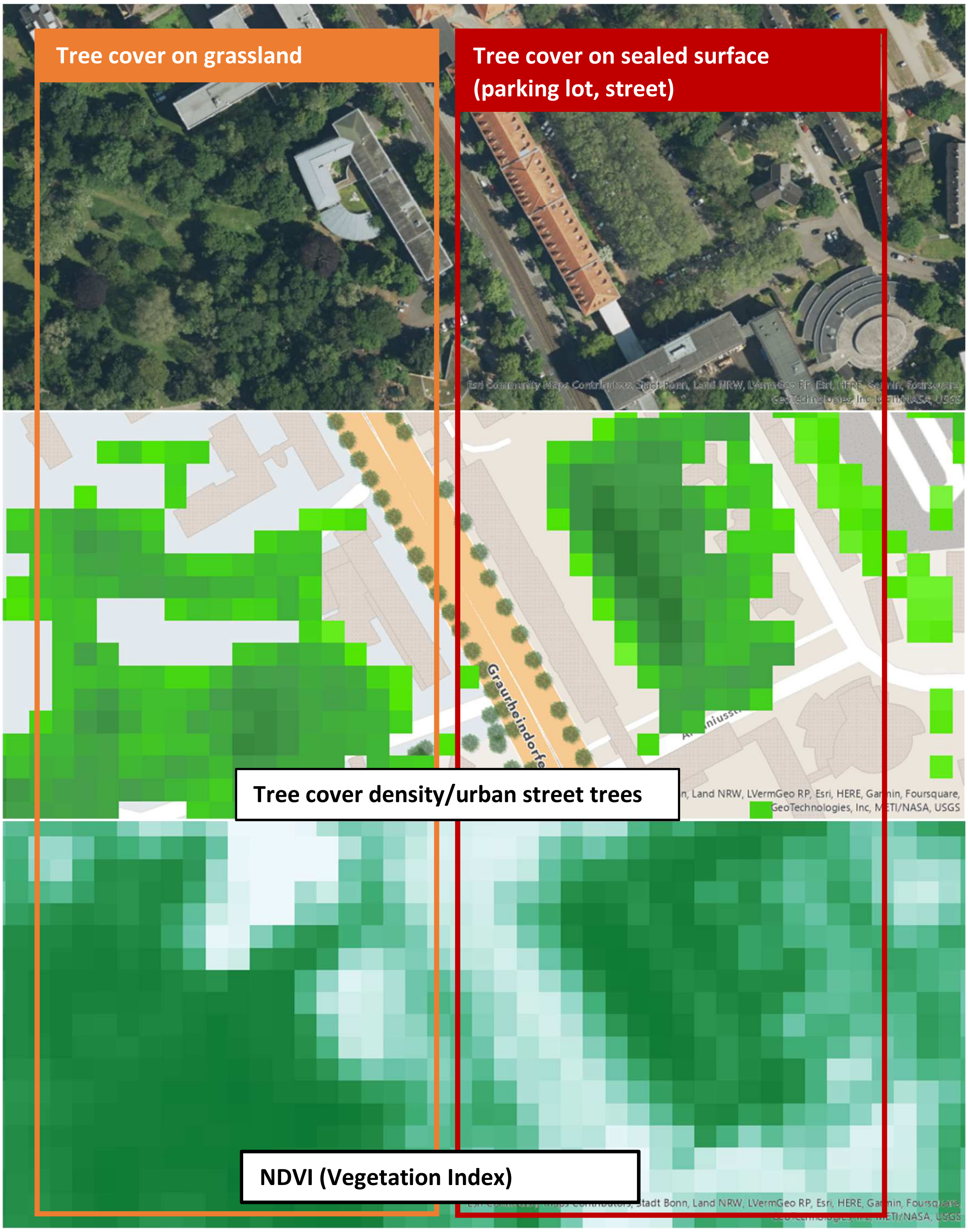

Figure 2: Remote sensing images from Bonn showing a tree-covered park, an alley and tree-covered parking lot from left to right. A) Aerial Image of the scene. B) Copernicus tree cover density overlaid on a street tree map. C) Normalized Difference Vegetation Index showing the greenness of vegetation.

Ecosystem service supply tables should provide information on baselines, whether it is zero or based on a hypothetical conversion to a different ecosystem type. Such information is particularly valuable, if there is a non-zero baseline service flow or if different baselines for the same service are used across different ecosystem types.

Spatial definition of baselines and the additivity of marginal flows: Measuring service flows may become increasingly complex when the service provision is non-linear in the extent of provisioning ecosystems. For instance, one could argue that carbon sequestration by forests is roughly a linear function of the number of trees, while flood protection by riparian forests upstream is non-additive. The flood protection provided by two neighboring forest patches is not equal to the sum of the individual protection provided by each forest. There are several reasons for this: i) simulating the forest to bare land conversion of several adjacent patches generates large run-offs that exceed the capacity of downstream forests to regulate or even eliminate the supply, ii) flooding caused by limited run-off on bare land accumulates non-linearly, iii) damages/outcomes like flooded areas downstream accumulate non-linearly, e.g. if a dike breaks, and iv) if large run-offs occur upstream, forests may dam up rather than retain water flows. This means that modeling the flood protection by forest in a given river basin (see the example in Figure 3 for the Elzbach River in Rhineland-Palatinate, Germany) depends crucially on the spatial delineation of the supply (orange) and use (red) areas as well as how the counterfactual of the supply area is defined. Note that this example is overly simplified, as supply and use occur in the same location in the river basin and are not always clearly distinguishable.

Furthermore, the spatial resolution at which the baseline is assessed clearly matters for some regulating services, where the damage being remediated accumulates spatially in a non-linear way (flood protection, local climate regulation, air filtration). However, its choice may also be limited by computational (simulating a large number of counterfactuals) or data (e.g. location/number of gauge measurements) limitations.

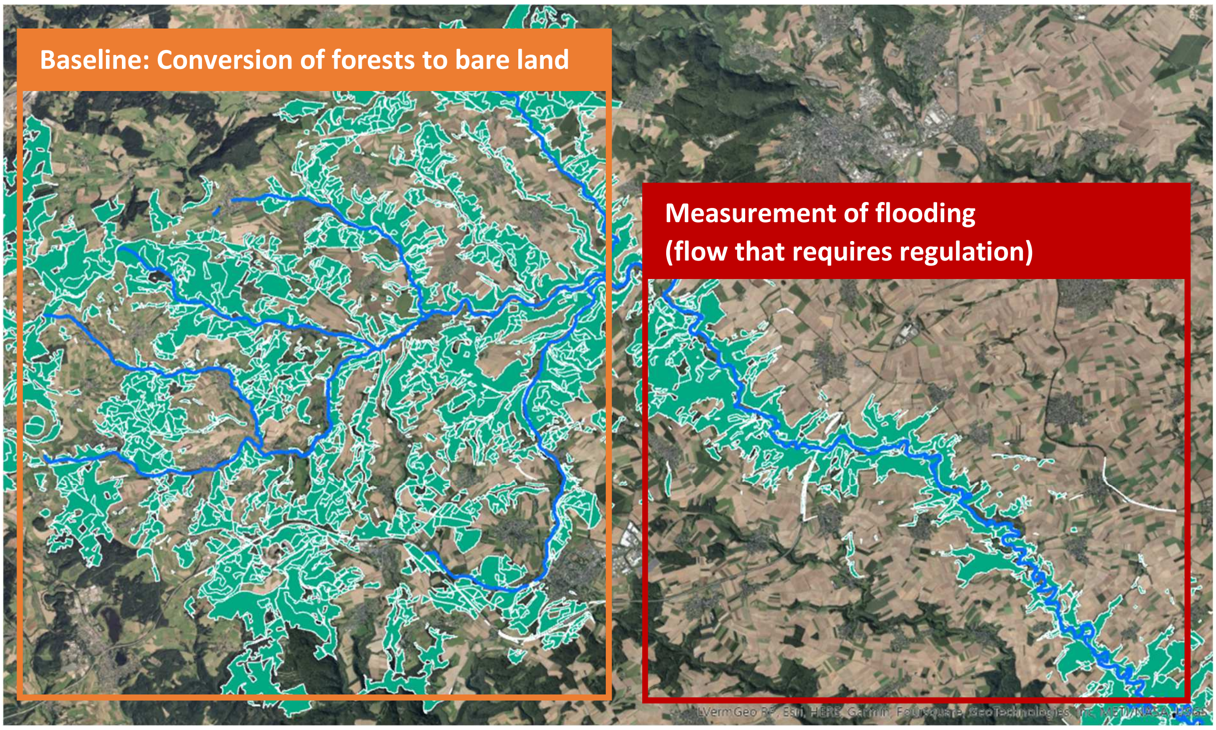

Figure 3: Forest patches (green) in the Elzbach river basin. Supply of the regulating service compared to a baseline (orange) and the use of the service downstream (red).

Compilers should include transparent information on what spatial resolution the service is modelled and whether the baseline is simulated for each or multiple ecosystem types, spatial unit of analysis (polygons, cells), administrative area or catchment areas.

2.2) Implementation challenges

Even under a well-defined baseline, there are empirical challenges to assess the baseline regulated stock/flow (if not observable) and the baseline service flow (if different from zero).

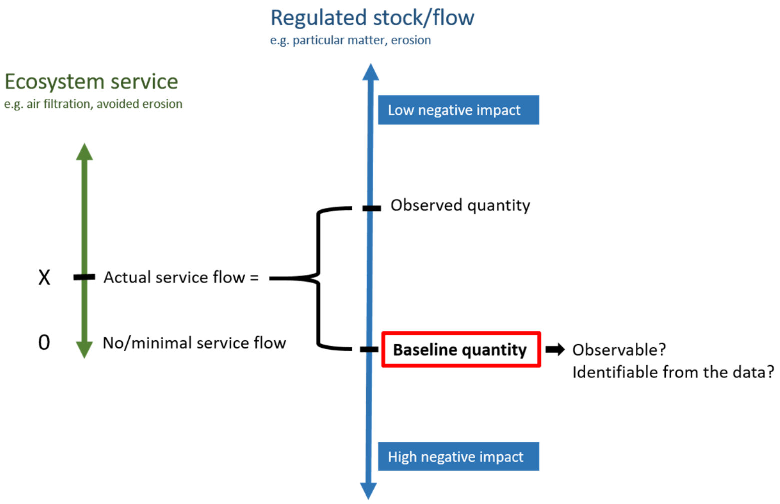

Figure 4: *Measuring or estimating baseline (and observed) quantities. Accounting for regulating ecosystem services requires that the regulated stock or flow can be observed and/or modelled.*

Identifying the baseline regulated stock/flow: For most services, we do not observe or know the baseline regulated stock or flow. For instance, how much erosion would occur on bare land compared to forest or what air temperature would we encounter in the absence of urban green spaces? These quantities have to be modelled/estimated.

As regulating services often mitigate negative impacts, the baseline quantity is typically higher than the observed quantity in physical terms (more erosion, pollutants, flooding). A baseline, even if ecologically and conceptually meaningful, is only useful if regulated stocks or flows can be identified for the counterfactual.

For some services the regulated flow can be modelled, for instance in the case for soil erosion ((Revised) Universal Soil Loss Equation). La Notte et al. (2021) propose that "*to better simulate the reference scenario lacking ecosystem protection, the maximum possible C-factor [for vegetation cover] corresponding to the lowest ecosystem potential to retain soil that can be found in the study area should be used*", meaning that the calibration is based on existing scientific literature and the study context.

For some services modelling may even not be feasible due to the complex spatial distribution. In the case of the air filtration service, spatial modelling the distribution of PM in the absence of different types of vegetation is challenging. This issue is also closely related to the spatial definition of baselines (see 2.1. above), which adds complexity to the issue. However, it can be approximated by estimating the counterfactual empirically (multiple regression framework) or by adjusting model parameters, e.g. the deposition velocity in the air filtration model.

Other services may have a more local effect, making it possible to estimate local counterfactuals. For local climate regulation, the air temperature in a non-vegetation scenario (the baseline) can be approximated using local predictions (from a multiple regression analysis).

In all these cases, the models are estimated or calibrated for a baseline scenario. Ideally, this is done by observing enough ecosystems of the baseline type or by values from the literature that are appropriate for the study context. For example, is there enough bare land surface in urban contexts to identify a corresponding surface cover coefficient (intersect) to predict temperatures in non-vegetated parks? Do we know deposition velocities for bare land in the study context to model air filtration?

If a service can be measured or modelled directly, e.g. CO_2 sequestered by trees, then the regulated baseline flow is defined implicitly and does not have to be separately assessed. The carbon retention service is a particular case, as it is challenging to asses not only the baseline quantity, but even the actual quantity (measurements for soil organic carbon are typically available only 0-30 cm or 30-90 cm). Using biophysical evidence that, even in the baseline scenario, carbon retention in a given year is at risk only in the top soil, the focus of retention could be changed from soil carbon to soil carbon-at-risk (which may be assessed).

2.3) Implications for Accounting

Common logic and practical feasibility are clearly important considerations when choosing appropriate baselines for measuring ecosystem services. However, the choice should also make sense from an accounting perspective and be meaningful to potential users.

- Decision-makers may be interested in the effect of ecosystem conversions on services for scenarios that i) are policy-relevant (e.g. artificial surfaces to urban green), ii) are likely to occur (forest to bushland) or iii) reflect degradation (peat bogs to grassland). Likewise, some conversions may not legally occur, e.g. forest to agricultural in Germany. While these user needs are important, a baseline for each service that follows a common logic (e.g. bare land as default baseline) still allows to evaluate all such comparisons at a given unit of analysis. This means, the service flow in each ecosystem type reflect a comparison to the baseline. Comparisons between ecosystem types are basically differences-in-differences. However, it is crucial to communicate this to users or to deliver ready-made service comparisons for the relevant conversions.
- It is also important to note that, although we can think of baselines as hypothetical conversions, such conversions may not lead to changes in the aggregate service provision at the margin, e.g. pollutants that are not filtered due to a conversion of a forest patch to bare land may be filtered by a forest nearby with excess service potential.
- It is therefore important to communicate to users that baselines do not necessarily represent the loss/gain of ecosystems in case of degradation/restoration.
- The production boundary is limited to “natural” ecosystems (even if anthropogenic ecosystems may have higher service provision than the baseline). Likewise, only “natural” ecosystems can function as baselines (even if anthropogenic ecosystems represent the minimal service provision).
- Monetary valuation is typically done by marginal values. The valuation approach should be appropriate for the chosen baseline (“additivity”) or, vice versa, the spatial definition of the baseline can follow the available monetary values.

2.4) A decision tree for baselines

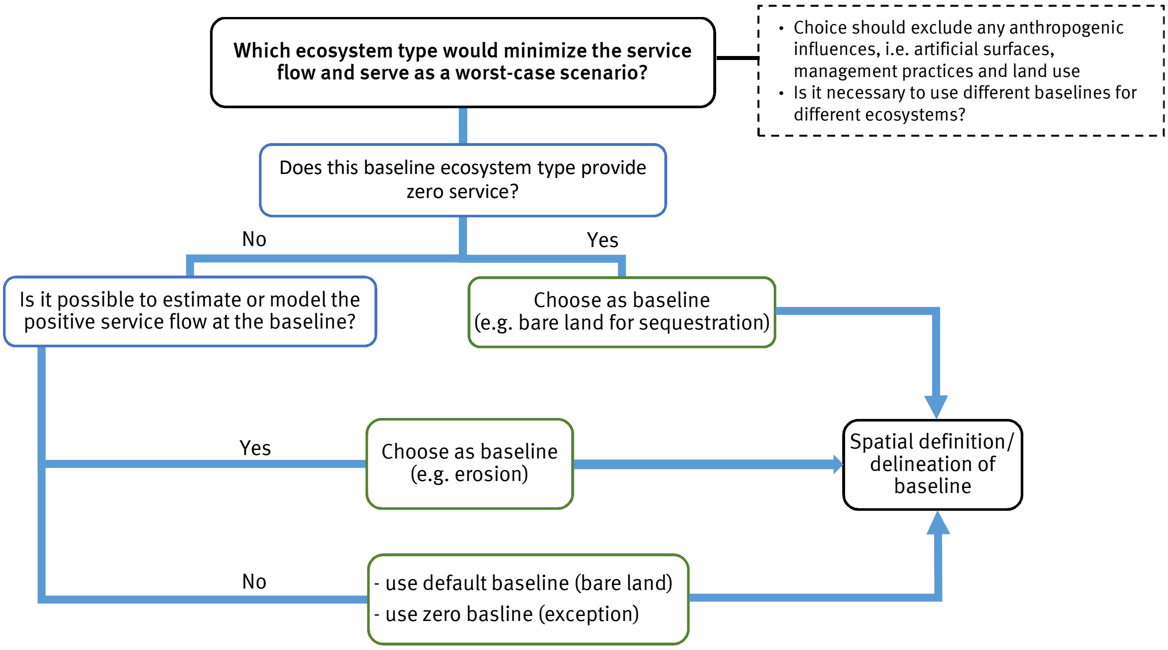

Figure 5: Tentative decision tree for choosing a baseline for a regulating ecosystem service in a standardized accounting framework.

3) Accounting for demand

The potential physical supply of ecosystem services is independent of the presence of nearby users. The general principles for accounting supply and use set out in the SEEA-EA define to whom services should be allocated conceptually, but not (always) how to identify users spatially and how much of the service should be attributed to them. To match potential supply to actual demand, service-specific attribution via spatial modelling can be used (Sutherland et al., 2018).

Typically, if the service is measured from the use side (e.g., water provision, recreation), demand is fully considered. In these cases, it may not be feasible or necessary to assess potential supply, e.g. how much recreation opportunity a national park can provide.

For services modeled from the supply side (e.g. local climate regulation, air filtration, flood protection), on the other hand, demand is often not or only partially considered. Strictly speaking, demand can be viewed as a combination of two factors: i) the presence of a stock or flow that generates a negative impact, e.g. pollutants or heat, ii) the presence of people and/or anthropogenic infrastructure that would benefit from a mitigation of said negative impact. If only one is considered in the modeling of the regulating service, this may lead to an overestimation of the service. Monetary valuation will distinguish users with no or positive valuation, but it is not automatically clear, whether a zero monetary value stems from an individuals’ preferences or a lack of exposure to the physical service. If values are imputed, e.g. spatially via value transfers to areas with positive physical services, it also matters to properly identify physical users in the first place.

3.1) Identifying demand

The presence of users that benefit from a service can be approximated by setting a spatial production boundary. Often this is done by assessing the service only for specific ecosystems, administrative areas or otherwise define spatial areas (e.g. commuting zones) that correspond roughly with areas of demand.

Local climate regulation can serve as an example of why this is a necessary but challenging exercise. For Bonn, Germany, the Local Administrative Unit (LAU, blue line in Figure 5) would be classified as a densely populated area (“city”) according to the Degree of Urbanisation (DEGURBA) or as part of an urban core of a functional urban area (OECD). This suggests that local climate regulation should be recorded for this unit (e.g. in the proposed amendment for EU Regulation 691/2011 Annex IX Ecosystem Accounts). The LAU includes a large forest area in the south, where temperatures are clearly below the built-up areas, suggesting a significant cooling effect may take place (Figure 5 left panel: Land Surface Temperature in August). However, this area is very distinct from the residential, commercial or public areas with high population and building density to the north (Figure 5 right panel: Population Density [red] and ecosystem type urban green space (green). In fact, most of the urban green spaces in the ecosystem extent account fall in that area almost by design, as we have delineated urban areas using an alternative attribute for continuous built-up areas in the German land cover model (“Ortslage”).

The issue with including a forest located within a “city” LAU, is that cooling effects that do not directly benefit economic units (households, businesses) would be incorrectly accounted for as a final ecosystem service. Cooling effects at the edge of the forest may benefit the surrounding built-up areas within a certain distance.

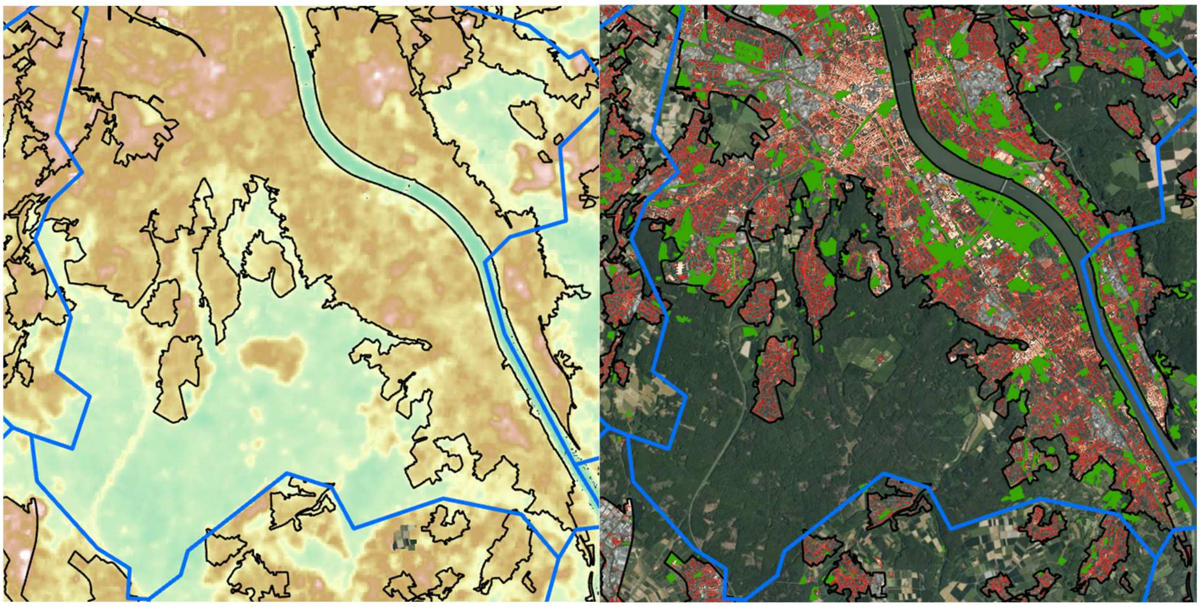

Figure 6: Demanding areas of local climate regulation (cooling effect) in Bonn, Germany. Left: Distribution of temperature and delineation of DEGURBA (blue line) and continuous settlement area (black line). Right: Population density (red) and urban green spaces (green).

3.2) Including demand

Even though a service is measured or modelled for all service providing areas (SPA), the actual flow can be accounted for those areas, where supply and demanding areas spatially overlap. For the example local climate regulation (urban cooling) this can be implemented as follows:

A buffer is set around each potential SPA (e.g. urban parks, forests) according to local climate regulation serving as cooling distance (CD). The CD can be adjusted depending on the size, shape and type of the SPA. It may range somewhere between 100 and 500 meters and is ideally calibrated to the local context. The CD represents the maximum ability of an ecosystem to cool down temperature (blue buffer in Figure 6).

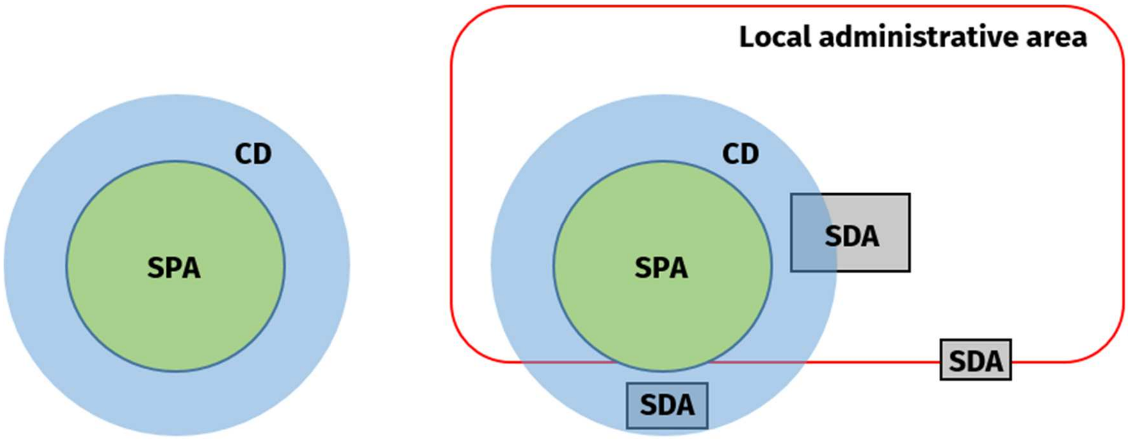

Figure 6: Service providing areas (SPA - green) and their cooling distance (CD – blue buffer) interact with service demanding areas (SDA - grey) outside and within a city (urban LAU - red).

As households are the final users or beneficiaries of the local climate regulation, we need information on their spatial distribution. A high resolution population dataset can be matched with the ecosystem extent account (artificial/built-up areas) and reveals the service demanding areas (SDA)[1]. The intersection between CD and SDA is therefore the spatial location of the actual service flow. These areas can be spatially aggregated at the administrative unit at which the service is reported, for example a city LAU.

Besides taking demand into account, this approach has two additional advantages: First, SDA which does not fall inside the CD represent the unmet/excess demand. SPA that are not in the vicinity of demand, provide information about "excess supply". Second, an additional indicator can be added to the use table. Besides reporting the average cooling effect on hot days and the number of hot days, the approximate number of users can also be indicated. Other indicators could inform about demand and/or use intensity of the service. Normalizing such indicator will give policy makers excellent insights on the service when comparing different, in this case LAU´s.

The caveat of this approach is that the cooling effect is only accounted for on artificial/built-up areas, as these are the only areas, where users can be located by geo-data. Cooling within parks that are frequented for recreation may not be accounted for, if there are no population counts for those areas. A compromise would be to account the cooling effect for areas at the intersect of CD and SDA and for SDA that are urban public green spaces (green areas in the right panel of Figure 5).

Demand should play a role for the accounting of all regulation services and is ideally incorporated consistently. However, service demanding areas for other services such as air filtration may not be as clear cut as in the example of local climate regulation.

[1] See Orta Ortiz and Geneletti, 2018 and Schirpke et al., 2019 for applications of this approach.

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