OPERAs

Operational Potential of Ecosystem Research Applications

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MS2.3 Preliminary report on knowledge gaps and demand for instruments

Authors:

Sven Lautenbach[1,3], Heera Lee[1], Anne-Christine Mupepele[2], Carsten Dormann[2], Martin Volk[3]

[1]University of Bonn, [2]University of Freiburg, [3]Helmholtz Centre for Environmental Research - UFZ

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Chapter 1

Introduction

Humans are part of natural ecosystems and they are dependent on processes and services delivered by nature. Understanding nature as a system from which people benefit is summarised under the concept of ecosystem services. This concept has seen an ongoing popularity, driven by the increasing human pressure on natural assets and their non-sustainable exploitation. The increasing interest in ecosystem services comes with a multitude of new approaches and methods to assess these services.

The Millenium Ecosystem Assessment report in 2005 [MA, 2005] led to an increased scientific consideration of the ecosystem service concept and introduced a first sound classification of ecosystem services. It was followed by Ash's report [Ash *et al.*, 2010] dedicated to practitioners with a detailed guideline on how to carry out an assessment, the TEEB reports [TEEB, 2011b, TEEB, 2011a, TEEB, 2012] and numerous other protocols and guidelines (e.g. [Ranganathan *et al.*, 2008], others listed in Milestone 2.1). These protocols are exclusively reporting the current state-of-the-art. None of it comprises an analysis of research gaps. Despite this lack of consideration in general reports, some recent articles investigated research and knowledge gaps, usually focusing on specific topics such as landscape connectivity [Mitchell *et al.*, 2013] or marine ecosystems [Liquete *et al.*, 2013].

Nevertheless, it is time to revise case studies on a broad range and to assess the knowledge gain in ecosystem services science over the previous years and the remaining gaps in order to direct future research. We assessed knowledge gaps based on a quantitative review published in 2011 [Seppelt *et al.*, 2011] and a recent ISI Web of Knowledge search, taking into account the crucial changes and numerous new studies. We analyse key points in the process of an ecosystem service assessment, such as the service investigated, the countries studied and tools used.

Chapter 2

Methods and data

Our analysis extends the study of [Seppelt *et al.*, 2011] that was based on publications found through an ISI Web of Knowledge search of articles up to 2010 with the search phrase `"ecosystem service" OR "ecosystem services" OR "ecosystem valuation"` in the title, which resulted in 460 studies in the past 20 years.

In an additional step we analyzed a sample from the subset of articles selected by the same search phrases published in the ISI Web of Knowledge from 01.01.2011 to 01.08.2013. For the new data set we included additional properties that were not used in the data set from [Seppelt *et al.*, 2011]. From the total 658 articles selected, we analyzed a sample of 259 articles from which 107 could be interpreted as case studies.

Since we have a different coverage of the two periods we decided to show them separately.

The ecosystem service categories been used are listed in table 2.1, p. 4. We ignore categories with a very small number of occurrences such as P4-P7, C2 and C5 for the category specific interpretation.

Table 2.1: Ecosystem service categories used during the analysis

ID	Ecosystem Service
	Provisioning
P1	Food
P2	Fresh Water: storage and retention of water; provision of water for irrigation, industry and for drinking.
P3	Fibre and Fuel and other organic raw materials: production of timber, fuel wood, peat, fodder, aggregates
P4	Inorganic resources (oil, minerals, etc), "Geological services"
P5	Biochemical products and medicinal resources
P6	Genetic Materials: e.g. genes for resistance to plant pathogens
P7	Ornamental species: e.g. aquarium fish and plants, shells, etc
	Regulating
R1	Air quality regulation: (e.g. capturing dust particles)
R2	Climate Regulation: regulation of greenhouse gases, temp., precipitation, and other climatic processes
R3	Water quantity regulation (e.g. ground-water recharge/ discharge; surface flow regulation, storage of water)
R4	Water quality regulation (e.g. waste treatment) retention, recovery and removal of excess nutrients / pollutants)
R5	Soil retention and erosion protection
R6	Natural Hazard mitigation/ disturbance regulation : flood control, storm and coastal protection
R7	Biological Regulation: e.g. control of pest-species and pollination
	Cultural and Amenity
C1	Cultural heritage and identity: sense of place and belonging
C2	Spiritual and artistic Inspiration: nature as a source of inspiration for art and religion
C3	Opportunities for tourism and recreational activities
C4	Aesthetic: appreciation of natural scenery (other than through deliberate recreational activities)
C5	Science and Educational services opportunities for formal and informal education and training
	Supporting
S1	Biodiversity and nursery: Habitats for resident or transient species.
S2	Soil Formation: sediment retention and accumulation of organic matter
S3	Nutrient Cycling: storage, recycling, processing and acquisition of nutrients

Chapter 3

Results

3.1 ESS categories

Both periods show that some ecosystem service categories are more frequently studied than others (cf. figure 3.2 and figure 3.1). The distribution has been modified between the two periods: the first period showed a more equal spread between the categories while period 2 is characterized by a stronger focus on some categories: Period 1 showed a relatively large share for the provisioning of food, fresh water as well as fibre and fuels (P1-P3), nearly all regulating services, recreation and tourism (C3), aesthetic services (C4), biodiversity and nursery (S1) and nutrient cycling (S3). In the second period, food provisioning (P1), climate regulation (R2), water quality regulation (R4), recreation and tourism (C3) and biodiversity and nursery moved stronger into the focus. This change might be due to the reduction of studies that applied lookup table approaches based on [Costanza *et al.*, 1997] or similar studies. Since those studies covered nearly all ecosystem service categories, this might have led to a more even spread between the categories in the first period of investigation.

It seems that there is a lack of case studies for a number of services: biochemical products and medicinal resources (P5), genetic material (P6), ornamental species (P7) but also for soil formation (S2), and spiritual and artistic inspiration (C2). For an integrated overview about the benefits that people obtain from ecosystem, we need to close that gap.

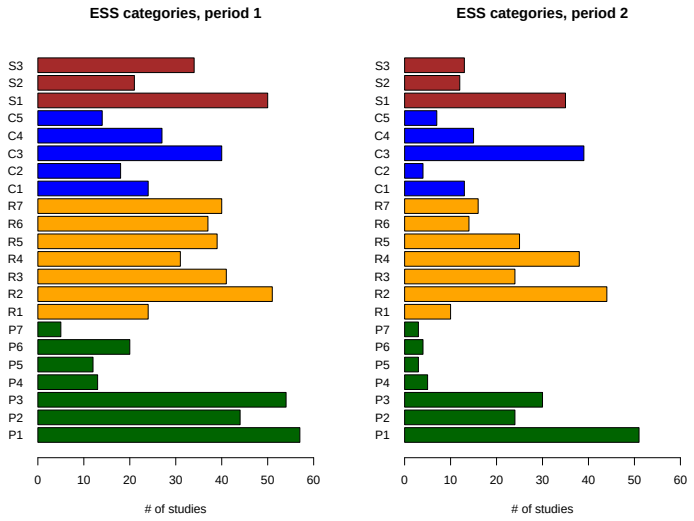

Figure 3.1: Number of studies in which the ESS type has been considered. The left subfigure shows the results till 31.12.2010 while the right subfigure shows the results for articles published from 01.01.2011 till 01.08.2013

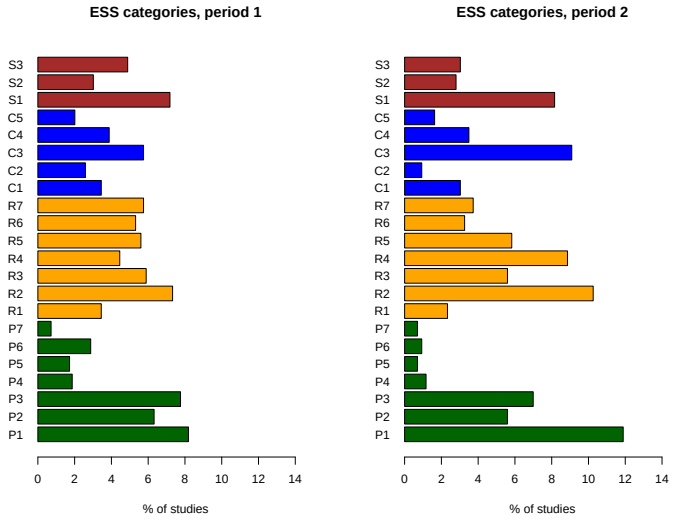

Figure 3.2: Percentage of studies in which the ESS type has been considered. The left subfigure shows the results till 31.12.2010 while the right subfigure shows the results for articles published from 01.01.2011 till 01.08.2013

3.2 ESS and scenarios

In both periods, the majority of studies does not consider any type of scenarios but analyses the current state (cf. fig 3.3, p. 8). So ecosystem service assessments are treated mainly as a static analysis without considering changes on both the demand and the supply side of services.

Any recommendation that ignores potential future developments is likely to be suboptimal. Climate change will effect ecosystems and thereby alter the services provided by them. In addition, climate change can be expected to change the demand for services, e.g. the demand for water quantity regulation is likely to be affected by changing growing conditions of crops.

Also, the link between ESS and demographic developments which is probably affecting both the demand side and the supply side of ESS is not well studied so far. Only a very small number of studies considers demographic change in their analysis. Demographic changes have to be expected in most regions and will probably effect the demand side as well as the supply side of ecosystem services. Ecosystem service assessments that ignore this will have a decreased practical relevance of for decision making since their results ignore the changes in demand and supply. A growing or shrinking population leads to an increase or decrease of the services. But also changes of aging change the demand for many services. Demographic changes are also leading to indirect effects on the supply side of ecosystem services, e.g. by changes of urban development which can be expected to effect ecosystems and the services produced by them (cf. [Haase *et al.*, n.d.]. Similarly, behavioral changes could also effect demand and supply side of ecosystem services.

In a nutshell, our analysis shows that ecosystem services should be more often applied together with scenario analysis.

This general distribution shows only a limited variance if differentiated by ecosystem service category (cf. fig 3.3, p. 8).

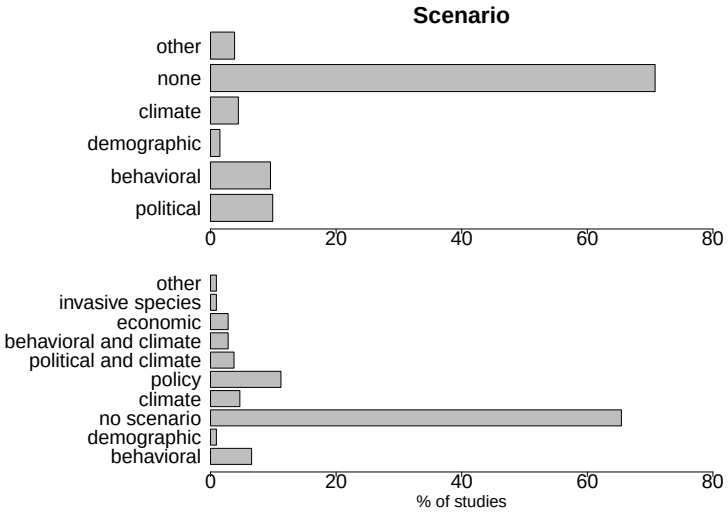

Figure 3.3: Scenarios used in the studies. The factor level *other* refers to cases in which insufficient information was provided in the paper to assign the article to a factor. The upper subfigure shows the results till 31/12/2010 while the lower subfigure shows the results for articles published from 01.01.2011 till 01.08.2013

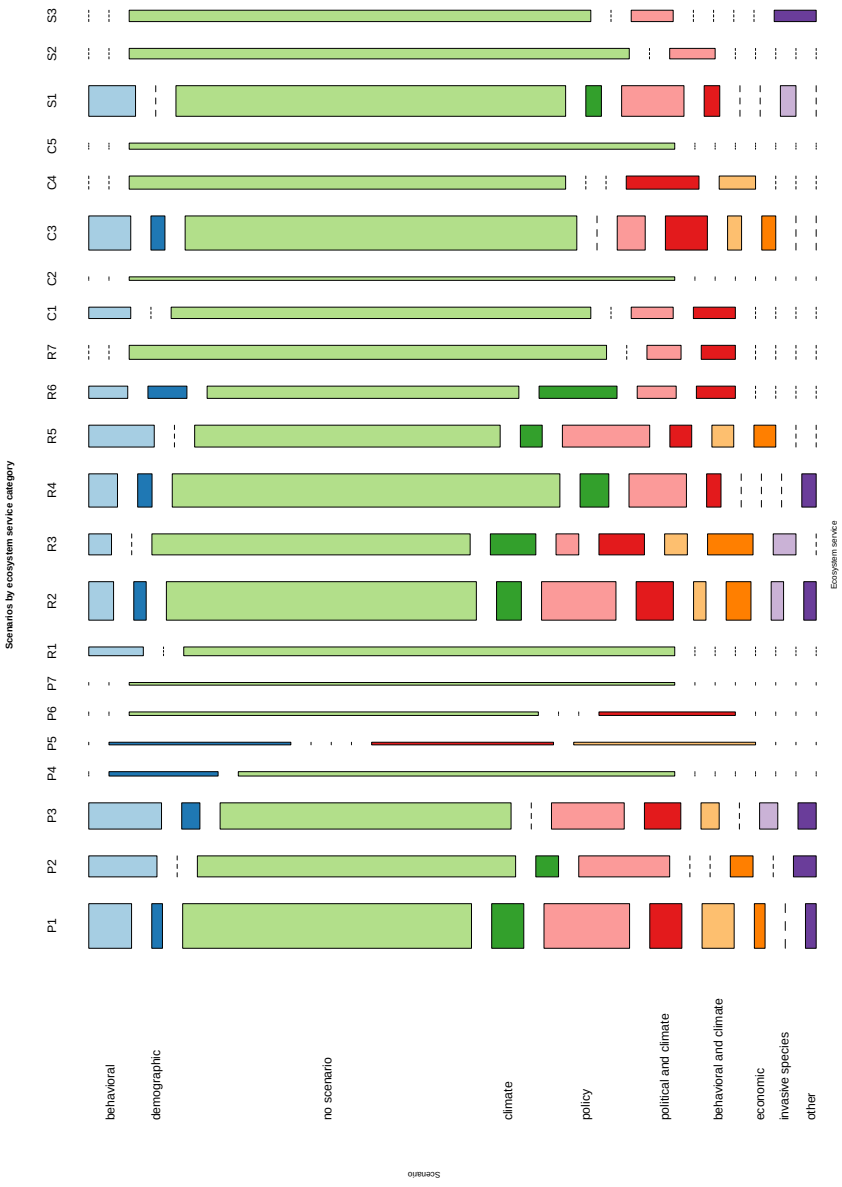

Figure 3.4: Scenarios used in the studies according to the ecosystem service categories. Results are only shown for articles published from 01.01.2011 till 01.08.2013

3.3 Countries studied

For both periods, a strong spatial bias can be observed: the USA and China are the countries with the most ecosystem services studies, while tropical countries especially in Africa are underrepresented. A more even spread of studies is desirable.

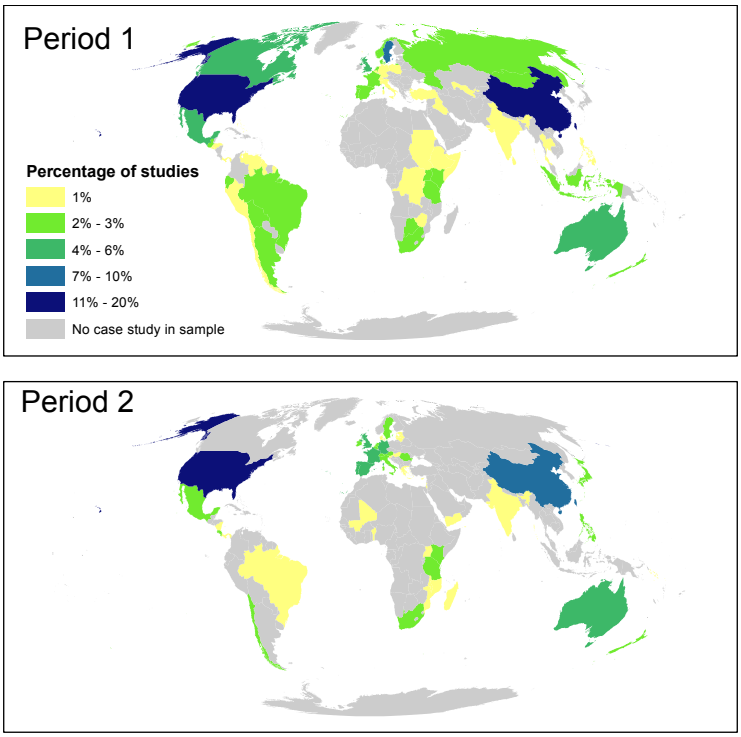

Figure 3.5: Spatial distribution of the case studies in the two periods.

3.4 Demand and supply side of ESS

The majority of the studies of the second period (property has not been analyzed in the first period) were focused on the supply side of ecosystem services (cf. figure 3.6, p. 11).

This pattern consists, if we look at the different ecosystem service categories (cf. figure 3.7, p. 12). We can identify some ecosystem service categories with a slightly increased percentage of demand side analysis or a combined demand and supply analysis, such as aesthetic services (C4) or tourism and recreation (C3), food provisioning (P1), fresh water provisioning (P2), or water quantity regulation (R3), but supply side analysis dominates the scene.

While the provisioning of services is an important issue if we want to value the realized or potential service provided by ecosystems, we need to know more about the demand for the services, especially the spatial distribution of the service.

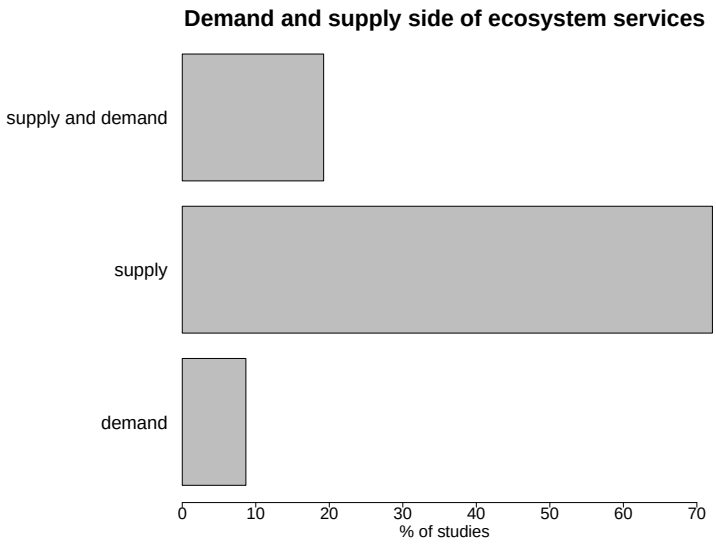

Figure 3.6: Percentage of studies which looked at the demand or the supply side of services. Results are only shown for articles published from 01.01.2011 till 01.08.2013

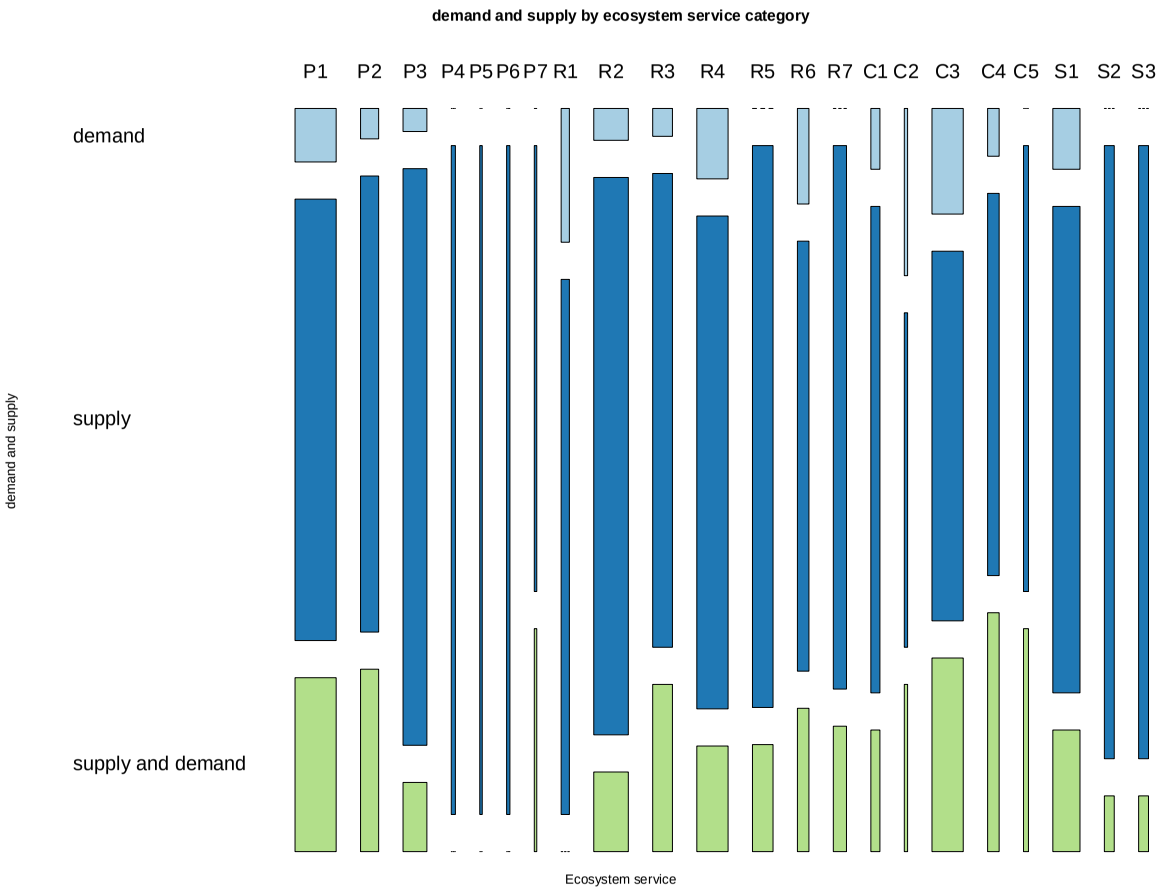

Figure 3.7: Percentage of studies which looked at the demand or the supply side of services, differenciated by ecosystem service category. Results are only shown for articles published from 01.01.2011 till 01.08.2013

3.5 Use of models in ESS case studies

While lookup tables and benefit transfer approaches dominated in the first period, this has changed in the second period. In the newer publications, models are used in the majority of studies (cf. figure 3.8). The most commonly applied models in the second period were statistic models and simple GIS approaches such as the tier 1 models in InVEST (cf. figure 3.9).

Pattern can be observed by looking at the different ecosystem service categories (cf. figure 3.10): process models play a larger role for water provisioning (P2) and soil retention/erosion control (R5), natural hazard mitigation (R6) and biological regulation (R7) are often analysed using statistical models.

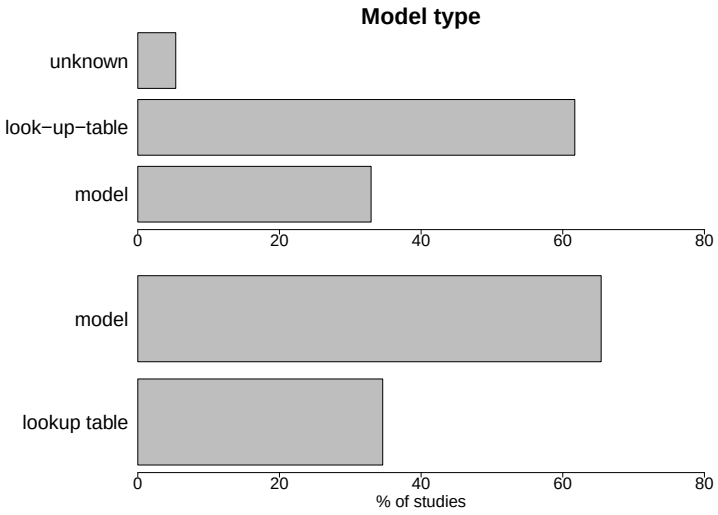

Figure 3.8: Model types used in the studies. The upper subfigure shows the results till 31.12.2010 while the lower subfigure shows the results for articles published from 01.01.2011 till 01.08.2013.

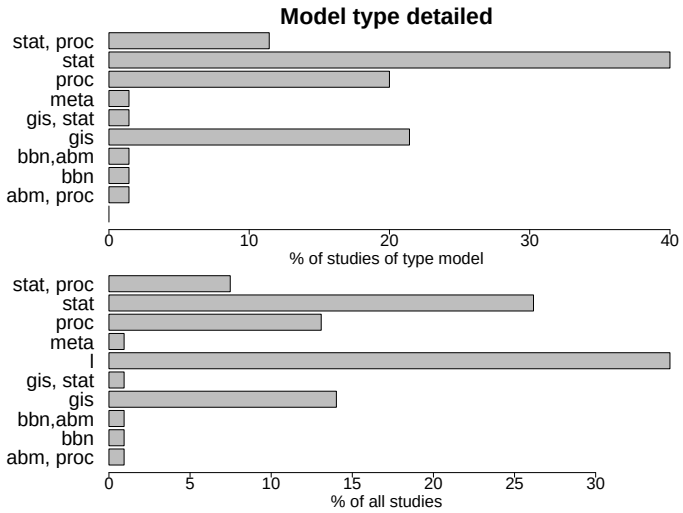

Figure 3.9: Details on model types used in the studies. Results are only shown for articles published from 01.01.2011 till 01.08.2013. Categories: l - lookup table approach, stat - statistical model, proc - process model, meta - meta analysis, bbn - bayesian believe network, abm - agent based model or individual based model as well as combinations.

Figure 3.10: Model types used in the studies according to the ecosystem service categories. Results are only shown for articles published from 01.01.2011 till 01.08.2013

3.6 Data source

Both periods are characterized by studies that relied on secondary instead of primary data sources (cf. figure 3.11). Categories such as biological regulation (R7), cultural heritage and the supporting services have been studied more frequently based on primary data (cf. figure 3.12). This distribution might reflect the different research tradition (e.g.a stronger focus on field work in biological sciences and social sciences compared) as well as the scale studied (at larger scales secondary data is likely to play a bigger role). The question remains open, if the secondary data used is appropriate for the ecosystem service case studies or if it was the only data set which was available.

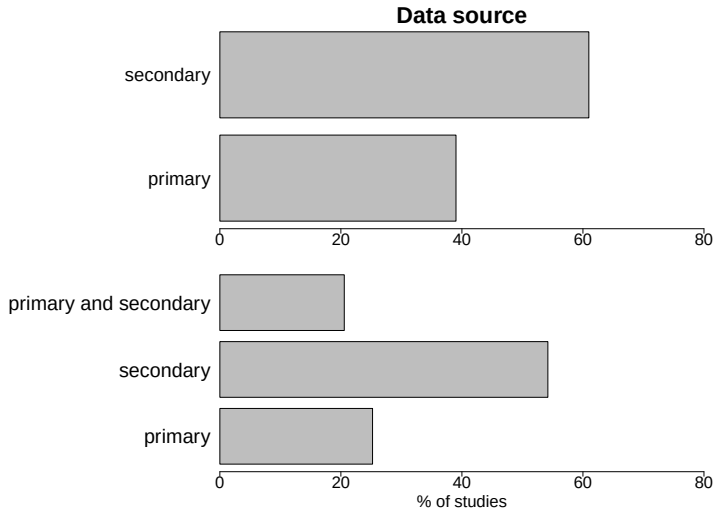

Figure 3.11: Data source used in the studies. The upper subfigure shows the results till 31.12.2010 while the lower subfigure shows the results for articles published from 01.01.2011 till 01.08.2013

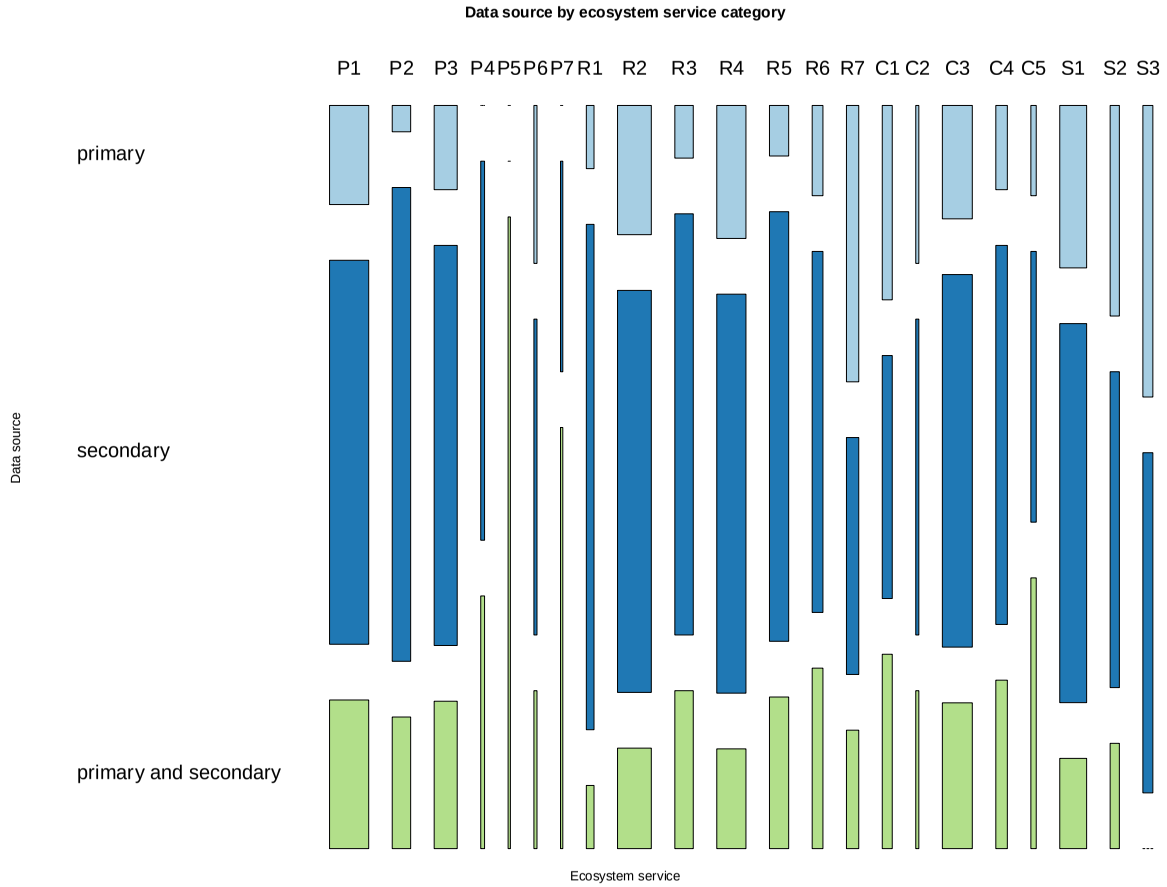

Figure 3.12: Data source used in the studies according to the ecosystem service categories. Results are only shown for articles published from 01.01.2011 till 01.08.2013

3.7 Indicators used

While the first period of our investigation was dominated by monetary indicators, this has been reversed in the second period: biophysical indicators (sometimes used in combination with monetary indicators) dominate the published case studies in the second period (cf. figure 3.13).

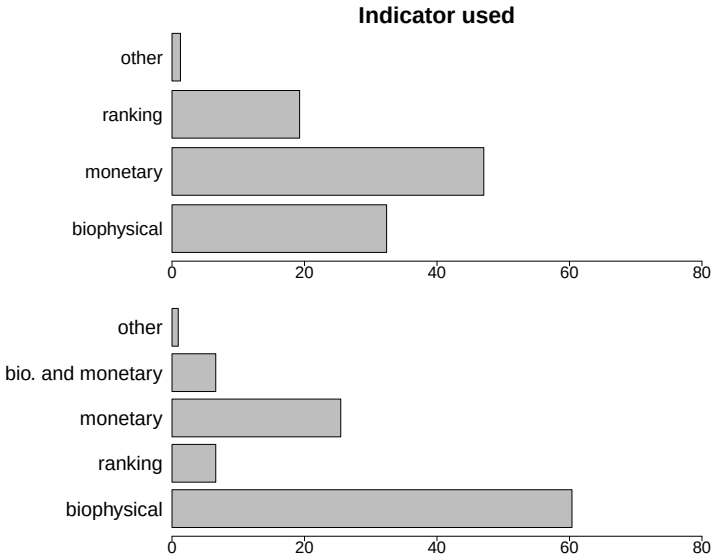

Figure 3.13: Indicator types used in the studies. The upper subfigure shows the results till 31.12.2010 while the lower subfigure shows the results for articles published from 01.01.2011 till 01.08.2013

Figure 3.14: Indicator types used in the studies according to the ecosystem service categories. Results are only shown for articles published from 01.01.2011 till 01.08.2013

3.8 System border definition

Case studies in the first period defined their system boundaries in about 42 percent by administartive boundaries and in 35 percent by biophysical boundaries (cf. figure 3.15, p.20). The second period shows a higher share of case studies which define their system boundaries by biophysical units.

The provisoning of ecosystem services can be thought of as beeing stronger linked to biophysical units while the demand side has a clearer connection to administartive boundaries. Therefore, one might expect system boundaries definition that reflect that. The data for the second period (cf. figure 3.17, p.22) do not really support this point of view: demand side studies have a slightly higher tendency to define system bouindaries by administrative units but this tendency is not very pronounced.

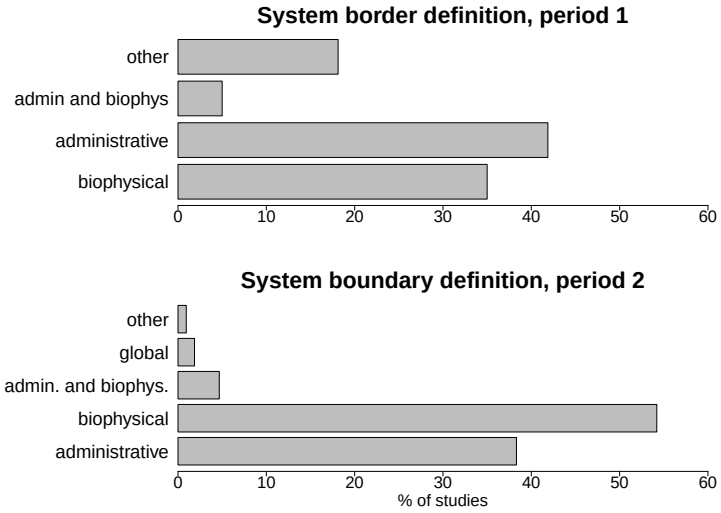

Figure 3.15: System border definitions used in the studies. The upper subfigure shows the results till 31.12.2010 while the lower subfigure shows the results for articles published from 01.01.2011 till 01.08.2013

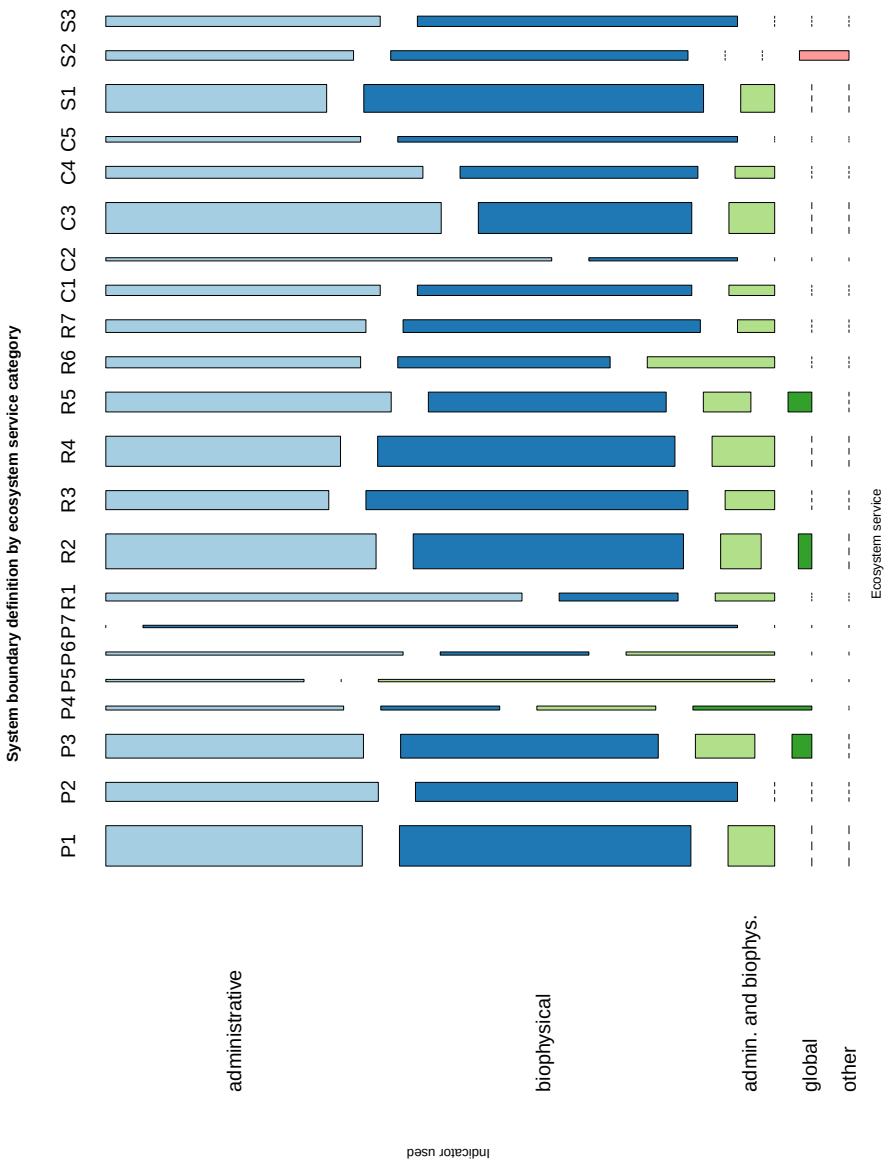

Figure 3.16: System border definitions used in the studies. Results are only shown for articles published from 01.01.2011 till 01.08.2013

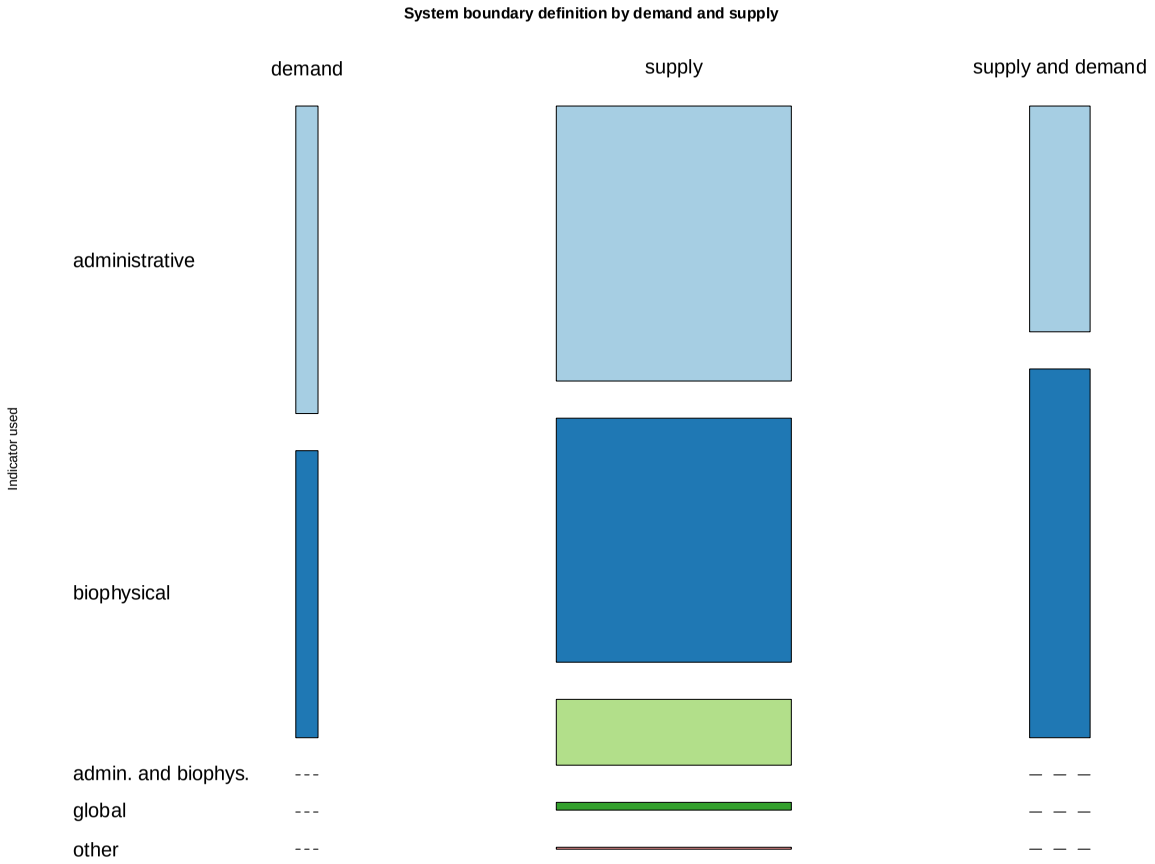

Figure 3.17: System border definitions used in the studies by demand and supply. Results are only shown for articles published from 01.01.2011 till 01.08.2013

3.9 Uncertainty

About half of the studies in both periods does not acknowledge any uncertainty in their results (cf. figure 3.18). Only about 25-30 percent of the studies report uncertainties in some quantitative way such as by standard errors, or by the results from a sensitivity analysis. Clearly, uncertainty is present in all of the ecosystem service case studies - not properly acknowledging it gives a wrong impression on the risk associated by a recommendation (if given at all).

An analysis by the different ecosystem service categories (cf. figure 3.19) shows differences that are presumably related to the different research traditions: fresh water provisioning (P2), food provisioning (P1), water quality regulation (R4), soil retention and erosion protection (R5) show a relatively high awareness of the need to quantify uncertainties. Cultural services generally show a low awareness of that need.

Case studies using process models and statistical models report more commonly uncertainties (cf figure 3.20), this is related to the use of models in the different research communities which map the different ecosystem service categories as well.

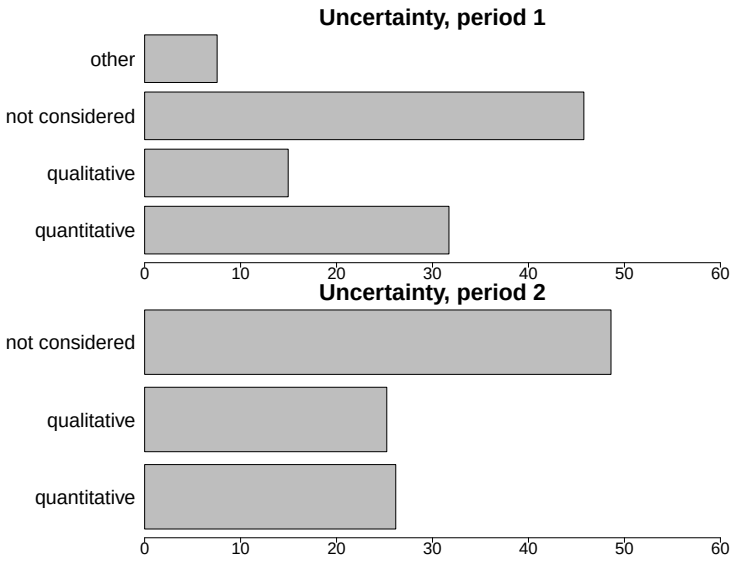

Figure 3.18: Uncertainty considered in the studies . The upper subfigure shows the results till 31.12.2010 while the lower subfigure shows the results for articles published from 01.01.2011 till 01.08.2013

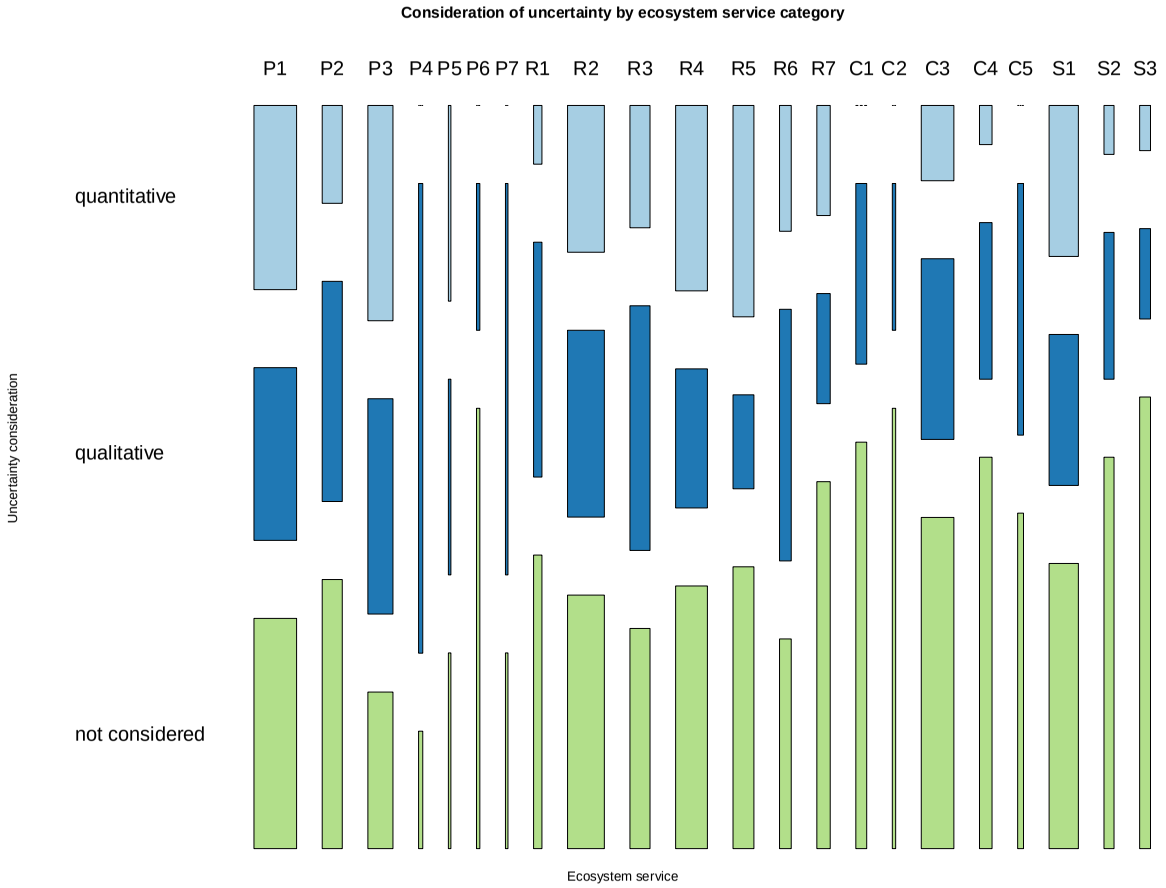

Figure 3.19: Uncertainty considered in the studies according to the ecosystem service categories. Results are only shown for articles published from 01.01.2011 till 01.08.2013

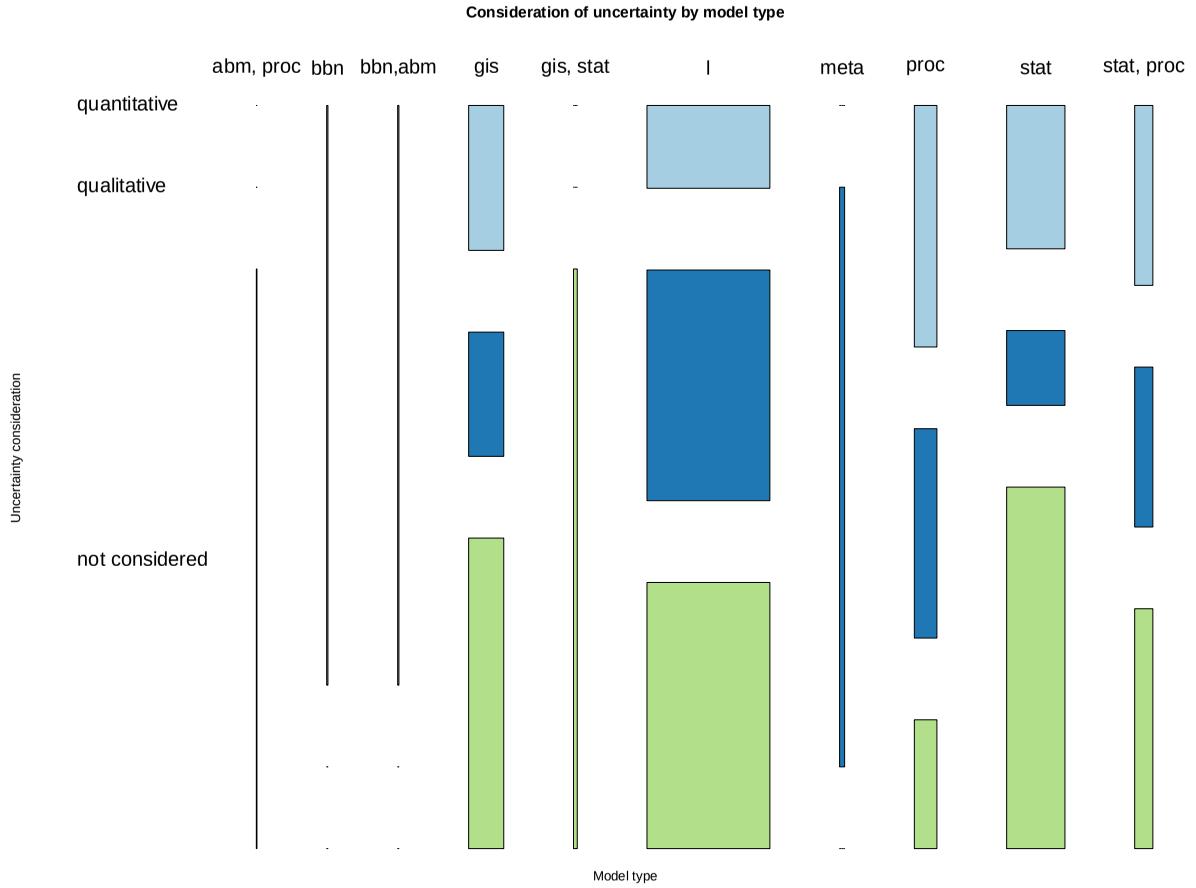

Figure 3.20: Uncertainty considered in the studies according to the model type. Results are only shown for articles published from 01.01.2011 till 01.08.2013

3.10 Validation

Results from the case from both periods are dominantly not validated (cf. figure 3.21). This is a serious drawback with respect to the reliability of recommendations based on the studies - and might be a reason why so many case studies stay away from giving any specific recommendation with respect to management decisions or spatial planning.

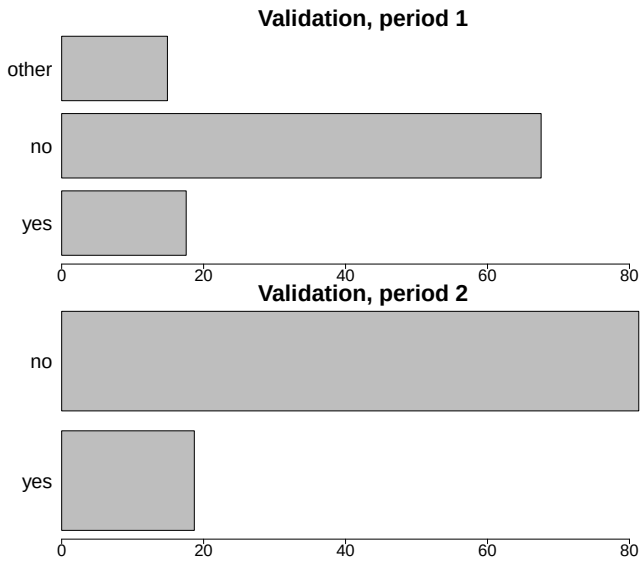

Figure 3.21: Validation of results performed in the studies. The upper subfigure shows the results till 31.12.2010 while the lower subfigure shows the results for articles published from 01.01.2011 till 01.08.2013

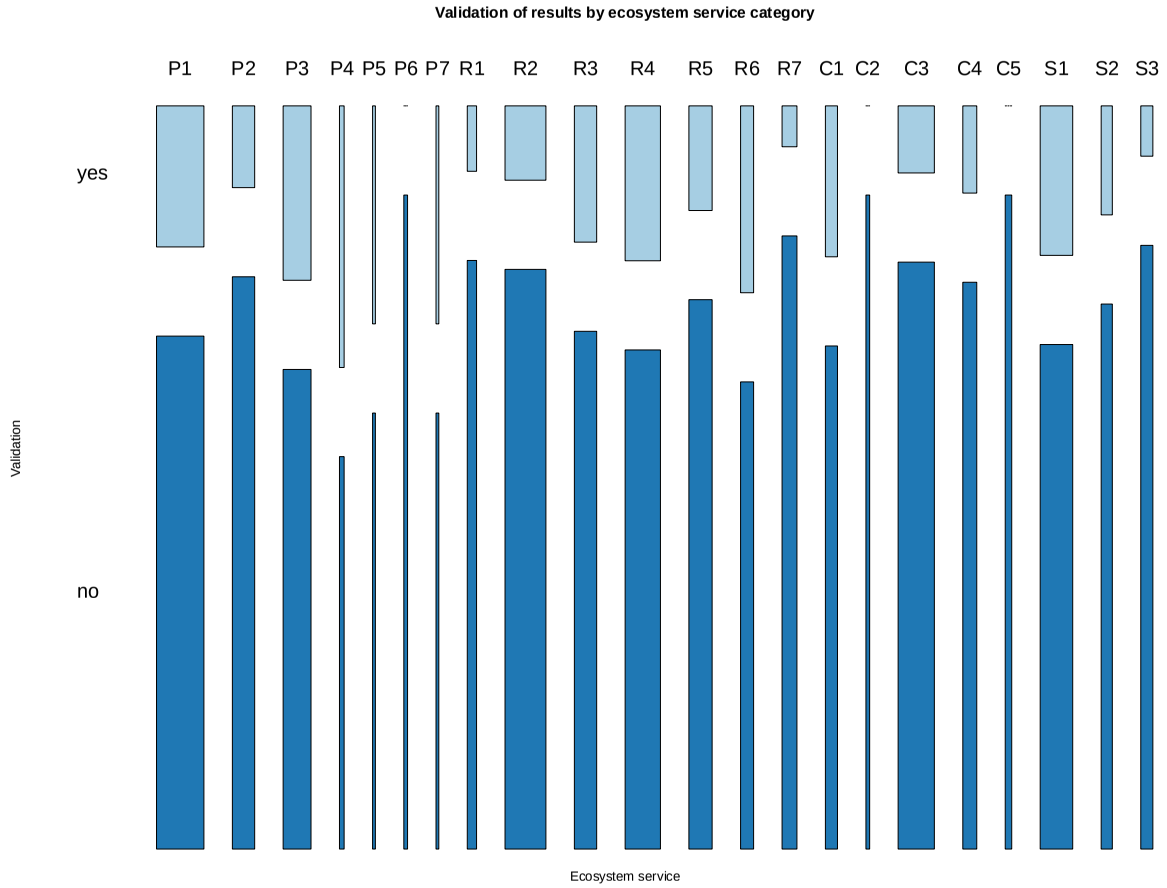

Figure 3.22: Validation of results performed in the studies according to the ecosystem service categories. Results are only shown for articles published from 01.01.2011 till 01.08.2013

3.11 Interaction between ecosystem services

Ecosystem services are frequently studied without consideration of interactions between them (cf. figure 3.23). While a large amount of studies looks at several services, most of them ignore any relationship between the services such as the effect of pollination on food production. The situation has even become worse in the second period. So even while more modelling approaches are used in the case studies, they lack integration.

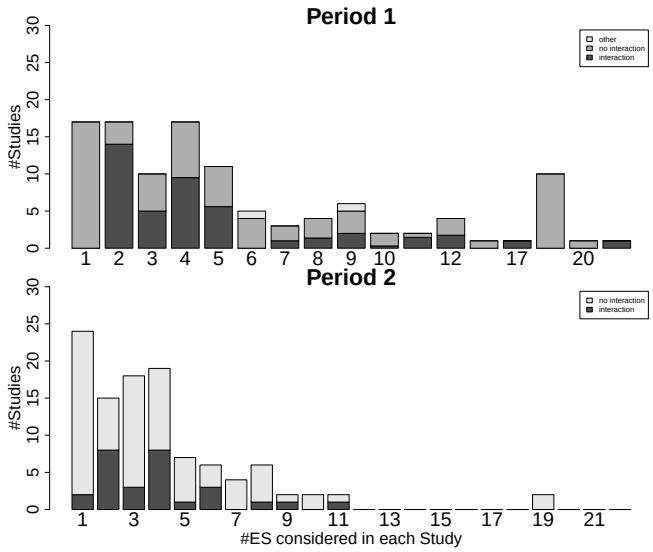

Figure 3.23: Number of studies which considered interactions between services by the number of eocsystem services considered in the study. The upper subfigure shows the results till 31.12.2010 while the lower subfigure shows the results for articles published from 01.01.2011 till 01.08.2013

3.12 Stakeholder involvement

Stakeholder have been involved in a relatively high number of studies in both periods (cf. figure 3.24) - still, a further incorporation of stakeholders would be beneficial. Stakeholders have been more strongly involved in studies on cultural services (cf. figure 3.25) - presumably because these studies tend to be based on interviews that include naturally the general public as a stakeholder. Hazard mitigation studies such as flood mitigation also involved stakeholder to a larger degree - probably to include information about vulnerability, effectivity of measures and regional impacts of hazards.

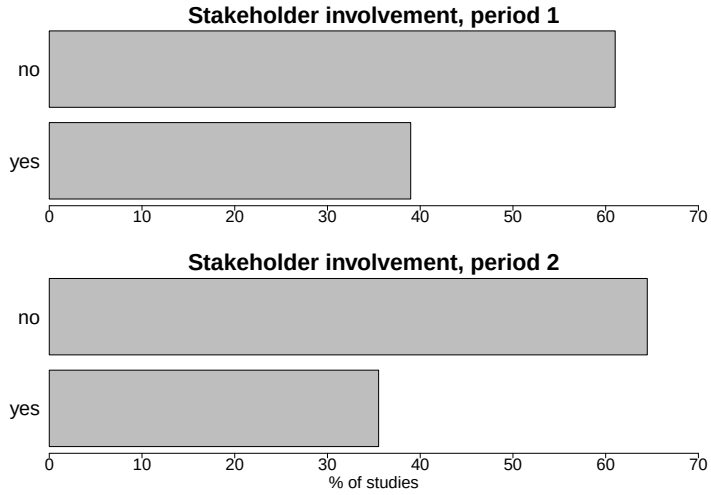

Figure 3.24: Stakeholder involvement in the studies . The upper subfigure shows the results till 31.12.2010 while the lower subfigure shows the results for articles published from 01.01.2011 till 01.08.2013

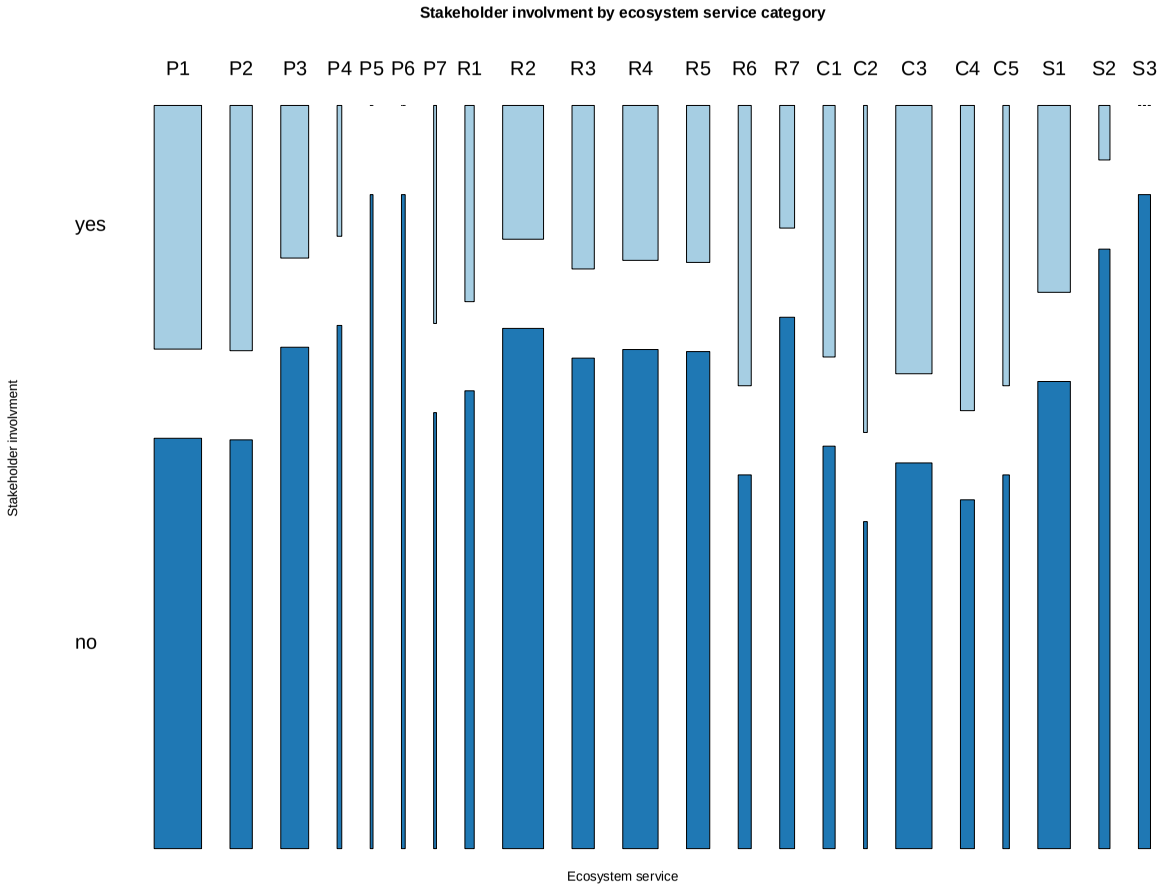

Figure 3.25: Stakeholder involvement in the studies according to the ecosystem service categories. Results are only shown for articles published from 01.01.2011 till 01.08.2013

3.13 Specific recommendation

The number of case studies which did not come up with some specific recommendation with respect to a specific decision is high in both periods: 78.5 respectively 77.6 percent of the studies (cf. figure 3.26). This is in line with the results from [Laurans *et al.*, 2013] who looked specifically at ecosystem service valuation studies.

High specific recommendations have been given for the few studies on spiritual and artistic inspiration (C2) and science and educational services (C5)(cf. figure 3.27).

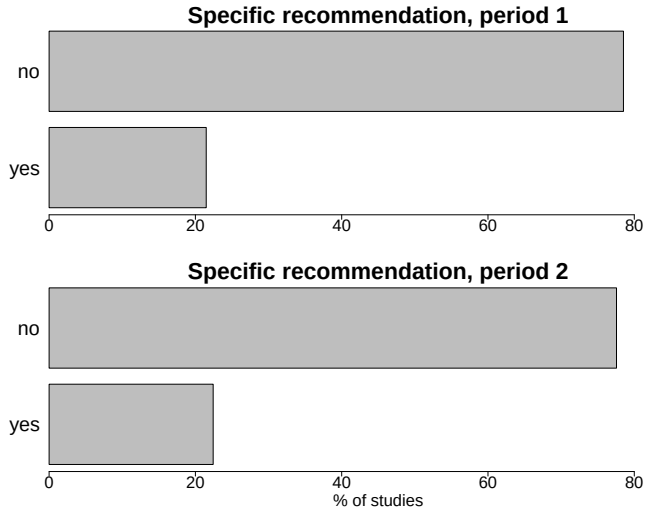

Figure 3.26: Specific recommendation given in the studies. The upper subfigure shows the results till 31.12.2010 while the lower subfigure shows the results for articles published from 01.01.2011 till 01.08.2013

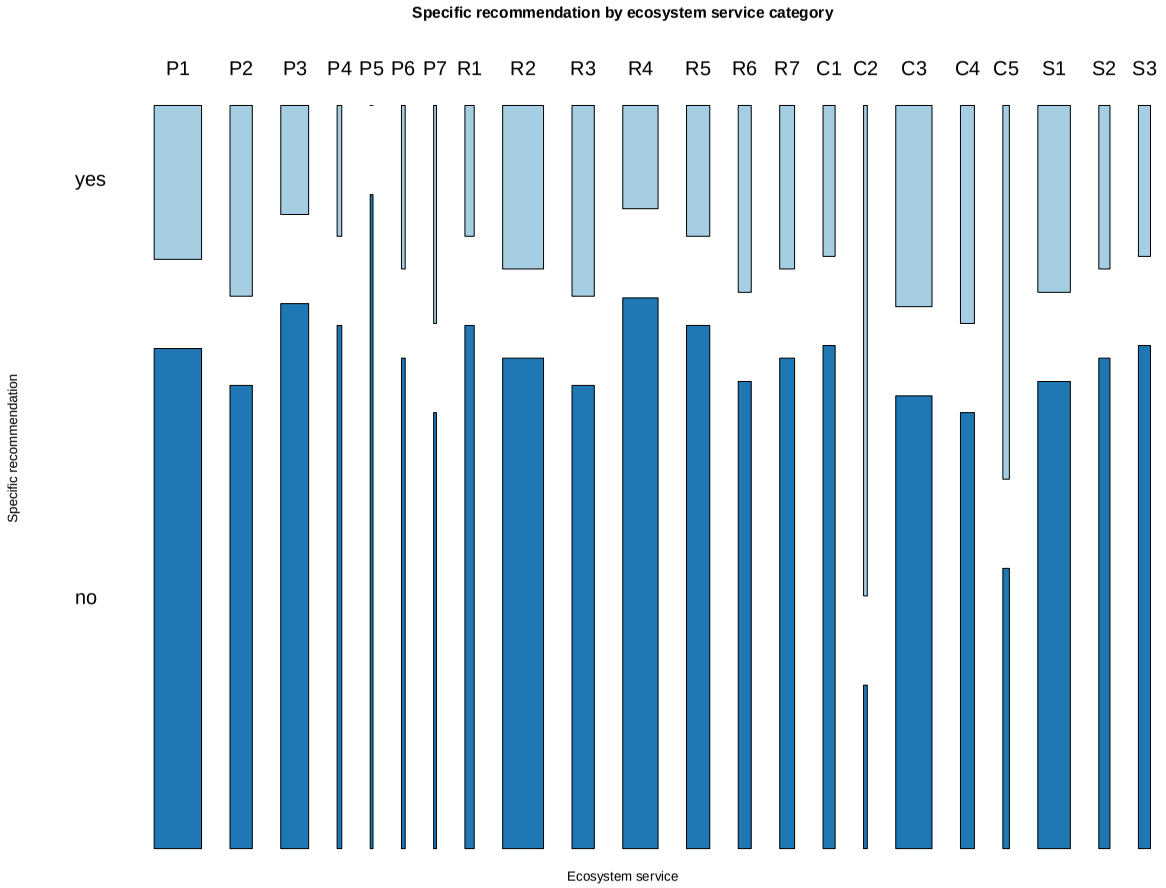

Figure 3.27: Specific recommendation given in the studies according to the ecosystem service categories. Results are only shown for articles published from 01.01.2011 till 01.08.2013

3.14 Mapping ESS

Mapping ecosystem services is relatively common in the second period of our investigation: 32.7 percent of the studies mapped ecosystem services (cf. figure 3.28). While there are clearly some ecosystem service categories being mapped more frequently than others, there is no ecosystem service category beside Ornamental species (P7, with a very small number of observations) that has not been mapped at all (cf. figure 3.29).

Clearly, results from GIS models are mapped more frequently than others (cf.figure 3.30).

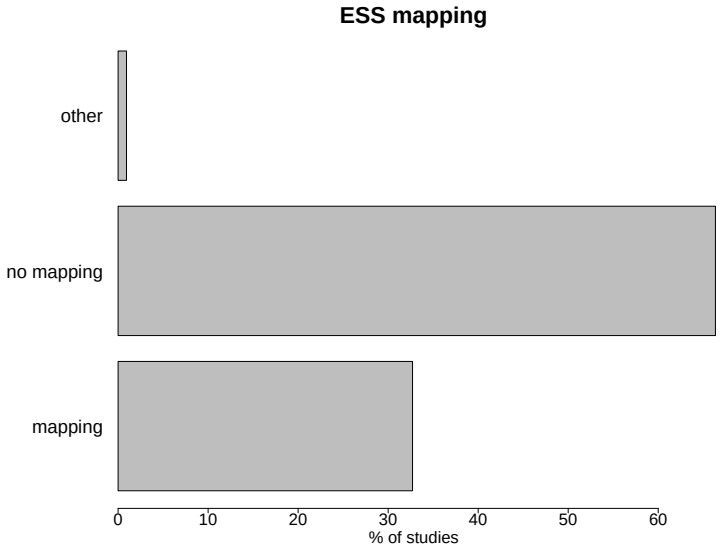

Figure 3.28: Mapping ecosystem services. Results are for articles published from 01.01.2011 till 01.08.2013

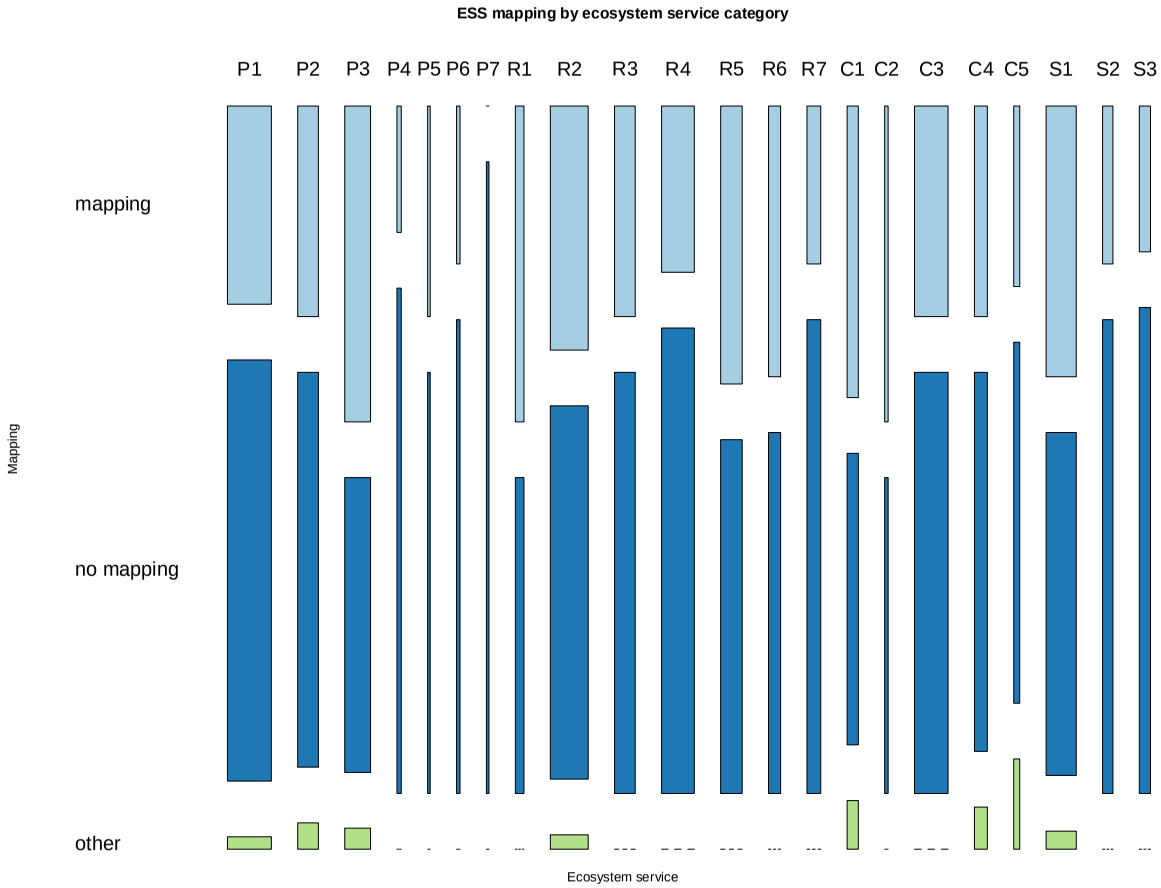

Figure 3.29: Mapping ecosystem services according to the ecosystem service categories. Results are only shown for articles published from 01.01.2011 till 01.08.2013

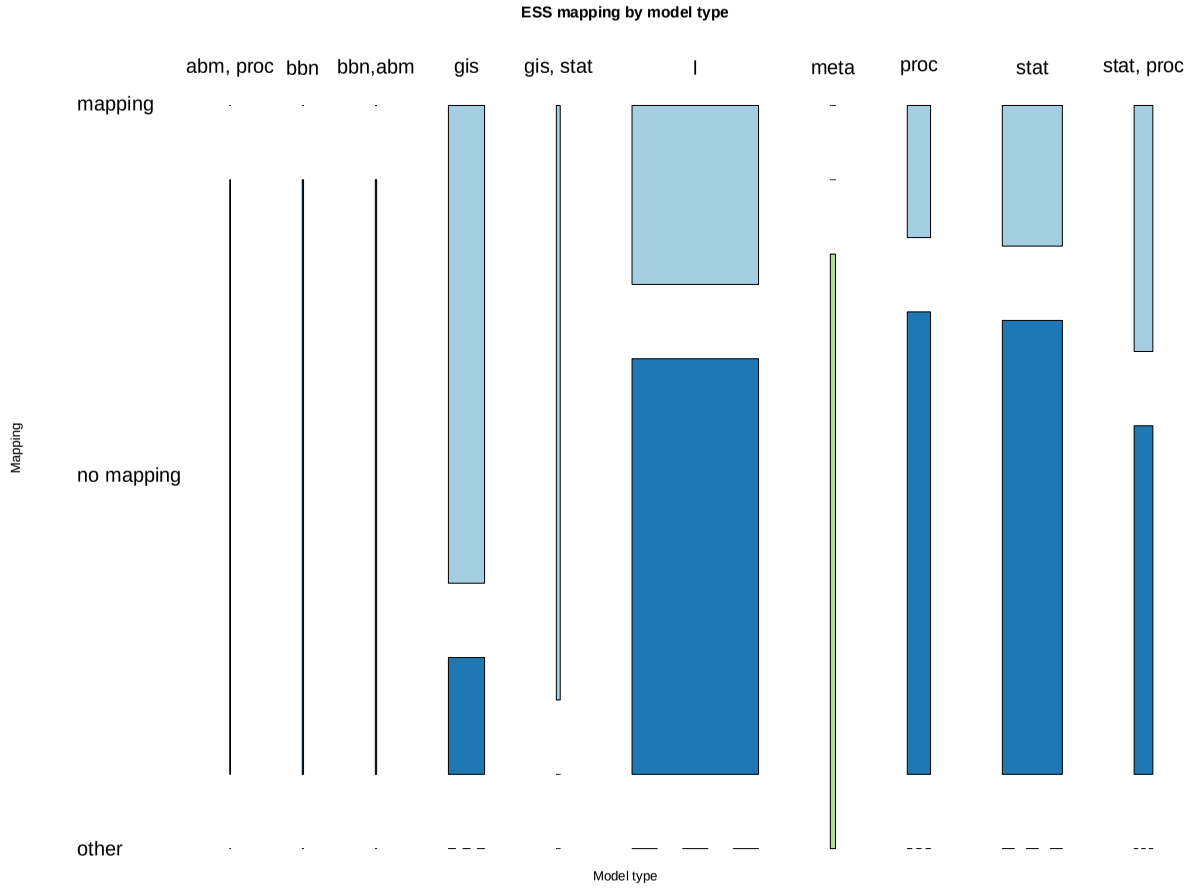

Figure 3.30: Mapping ecosystem services according to model type. Results are only shown for articles published from 01.01.2011 till 01.08.2013

3.15 Trade-off analysis

69.2 percent of the studies in sample of the second period do not analyse any trade-offs (cf. figure 3.31). But 18.7 percent perform a trade-off analysis that is more sophisticated compared to a simple map overlay analysis which accounts only for trade-offs by location.

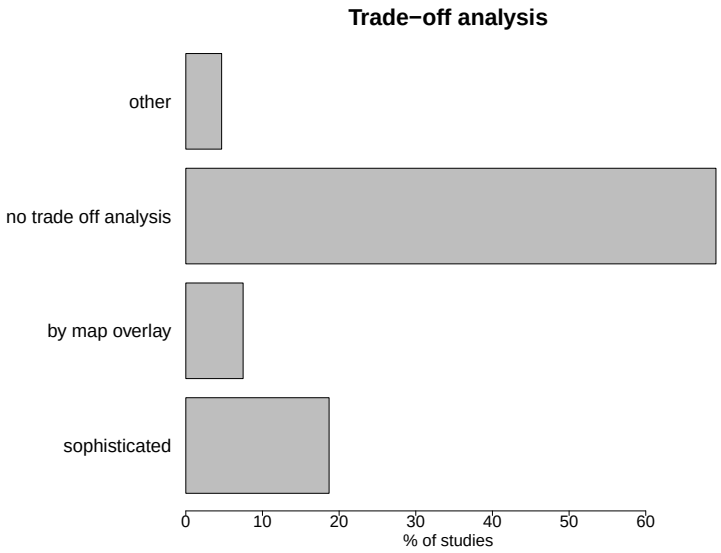

Figure 3.31: Trade-off analysis used in the studies . Results are shown for articles published from 01.01.2011 till 01.08.2013

The analysis of trade-offs is correlated with the level of model integration: case studies, that consider ecosystem service interactions, tend to use on average more trade-off analysis (cf. figure 3.32). These studies do not use map overlays for the trade-off analysis: the integrated nature of the models allows a trade-off analysis directly from the model outputs.

Map overlay approaches to assess trade-offs between ecosystem services are used in lookup-table approaches, GIS model and to a lesser degree in statistical modelling approaches (cf. figure 3.33). Lookup table approaches that consider trade-offs in a more sophisticated way are typically willingness-to-pay studies which quantify trade-offs between services based on the questionnaire. Trade-off analysis in process models is done based on a number of different model simulation runs with different parameters.

The relationship between the type of trade-off analysis and ecosystem service category (cf. figure 3.34) can be explained by the different model types used in the different ecosystem service categories (cf. figure 3.10).

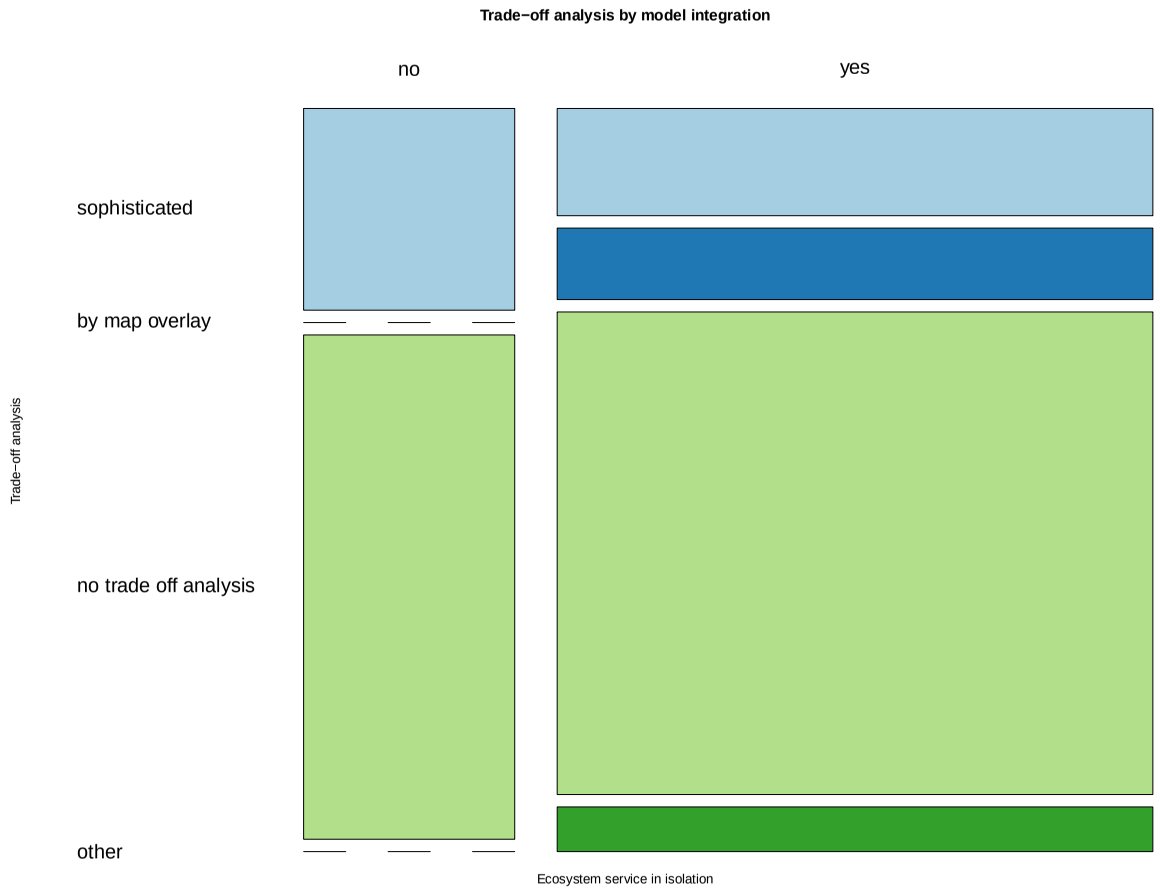

Figure 3.32: Trade-off analysis used in the studies by level of model integration. Results are shown for articles published from 01.01.2011 till 01.08.2013

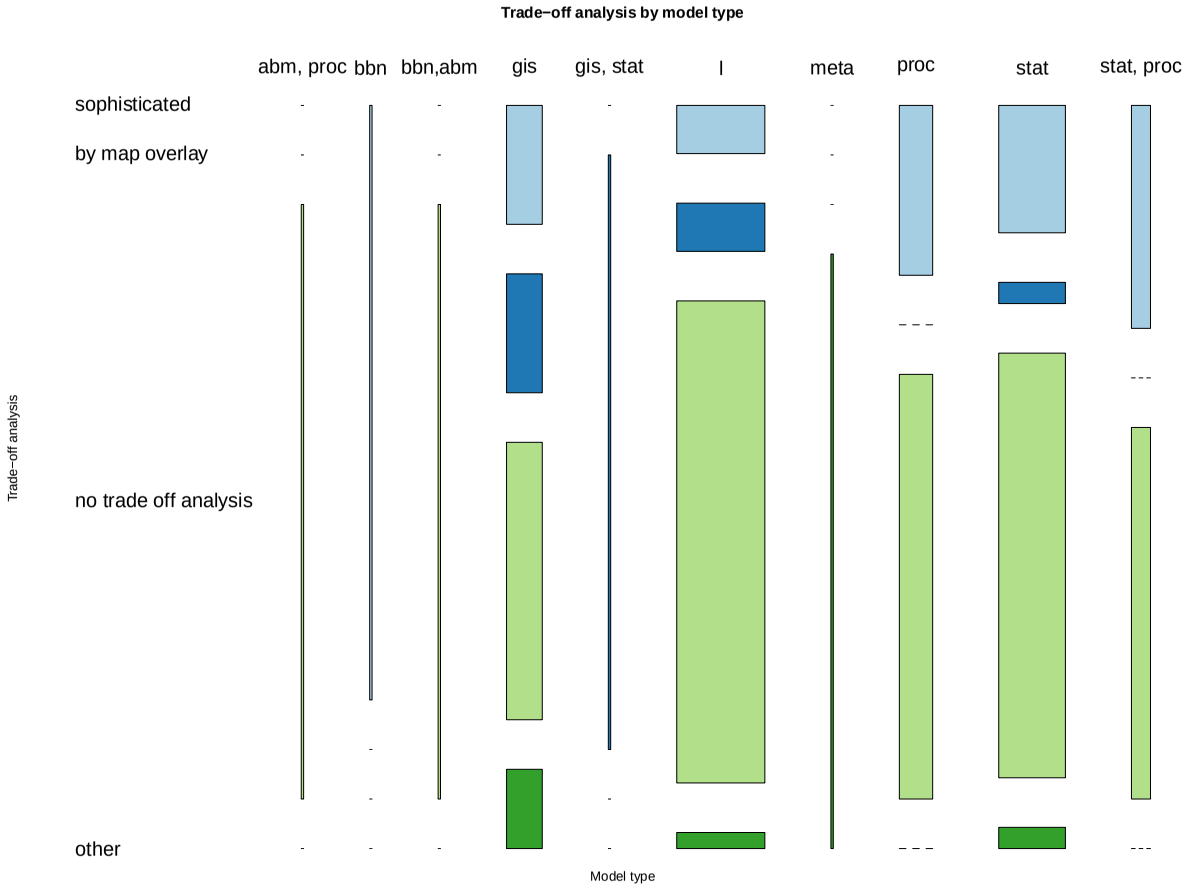

Figure 3.33: Trade-off analysis used in the studies by model type. Results are shown for articles published from 01.01.2011 till 01.08.2013

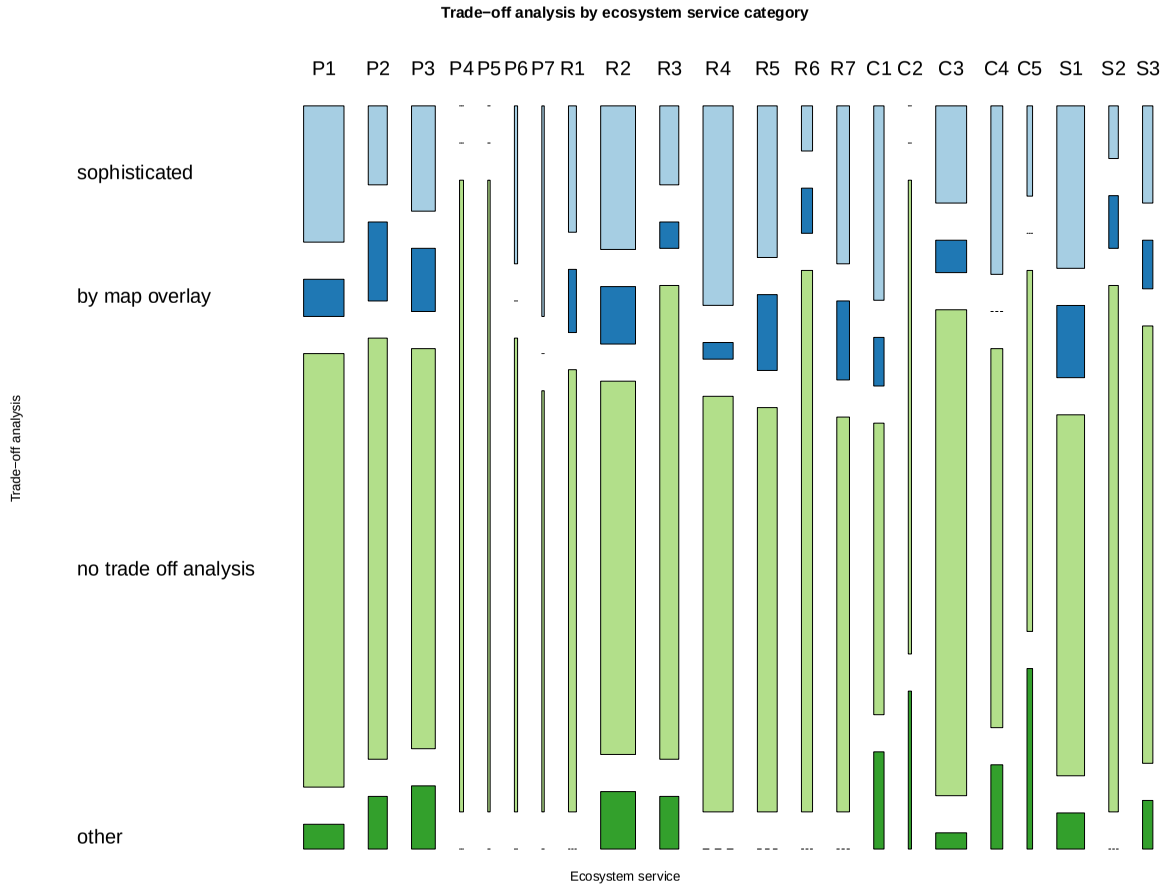

Figure 3.34: Trade-off analysis used in the studies according to the ecosystem service categories. Results are only shown for articles published from 01.01.2011 till 01.08.2013

3.16 Offsite effects

While the sample from the first period contained no analysis of offsite effects, we found 10 articles that considered offsite effects in the second period. While this is a positive trend, offsite effects are still largely underrepresented in ecosystem service case studies.

3.17 Instruments

The case studies in the sample of the second period did mostly not consider any instruments. The few exceptions are mentioned in figure 3.35. Only PES appeared several times.

On the other hand, a number of recent publications provided reviews on instuments (e.g. [Helming *et al.*, 2013, Kumar *et al.*, 2013, Broekx *et al.*, 2013, Karjalainen *et al.*, 2013, Geneletti, 2013, Honrado *et al.*, 2013]).

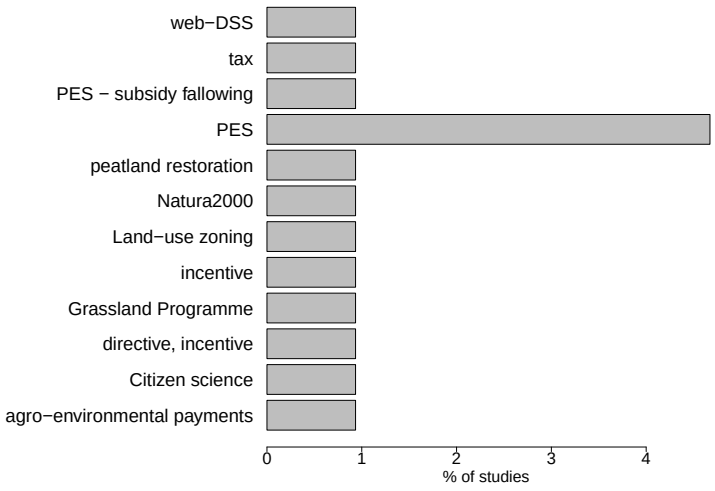

Figure 3.35: Instruments used in the articles published from 01.01.2011 till 01.08.2013

Chapter 4

Summary

On the base of the investigation of [Seppelt *et al.*, 2011], where 460 studies were analyzed (20 years back from 31.12.2010), we reviewed another 259 studies for the period of January 1, 2011 to August 01, 2013. Several knowledge gaps were identified.

1. The first period, analyzed by [Seppelt *et al.*, 2011], showed a more equal spread between the categories. In contrast, period 2 (that we investigated) is characterized by a stronger focus on some categories. Period 1 showed a relatively large share for the provisioning of food, fresh water as well as fibre and fuels, nearly all regulating service, recreation and tourism, aesthetic services, biodiversity and nursery and nutrient cycling. In the second period, food provisioning, climate regulation, water quality regulation, recreation and tourism and biodiversity and nursery moved stronger in focus.

2. We found that there is still a lack of case studies for a number of services such as biochemical products and medicinical resources, genetic material, ornamental species but also for soil formation, and spiritual and artistic inspiration. For an integrated overview about the benefits that people obtain from ecosystem, we need to close that gap.

3. A surprising result was that the majority of studies does not consider any type of scenarios but analyses the current state. That means that the current ecosystem service assessments are treated mainly as a static analysis without considering changes on both the demand as well as the supply side of services. We recommend that ecosystem services should be more often applied together with scenario analysis (including demographic scenarios): Any recommendation that ignores potential future developments suboptimal.

4. In both periods the most studies on ecosystem services have been carried out in the USA and China, while tropical countries especially Africa have been underrepresented. A more even spread of studies between is desirable.

5. The majority of the studies were focused on the supply side of ecosystem services. But while the provisioning of services is an important issue if we want to value the realized or potential service provided by ecosystems, we need to know more about the demand for the services, especially the spatial distribution of the service.

6. There is a change regarding the use of models in ESS case studies: The analyzed studies from the first period used mostly simple lookup table and benefit transfer approaches. In contrast, in the newer publications models are used in the majority of studies. However, the most commonly applied models in period 2 have been statistic models and simple GIS approaches such as INVEST and not integrated or process-based models. Integrated models that consider functional relationships between services are widely missing and need to be developed to do justice to the integrative concept of ecosystem services. That means also that projects analyzing trade-offs and offsite effects are still largely underrepresented in ecosystem service case studies.This shortcoming needs to be overcome, because it is a major strength of ecosystem services assessment.

7. Both periods are characterized by studies that relied on secondary instead of primary data sources. The question is how suitable and accurate these data are for the ecosystem services assessments (see also point 9)

8. Although stakeholders have been involved in a relatively high number of studies in both periods, there is still a further incorporation of stakeholders needed (otherwise the practical relevance of the results of ecosystem service case studies remains limited). This becomes obvious with the result hat i) mostly no specific recommendations with respect to management decisions or planning processes are made, and ii) the effect of policy instruments is not commonly analyzed in case studies.

9. Results from the case from both periods are mostly not validated. This is a serious drawback with respect to the reliability of recommendations (if given) based on the studies (see also point 8). Similar conclusions can be drawn for the quantification of uncertainties - especially the studies dealing with cultural services seem to be unaware of the need of a proper quantification of uncertainties

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