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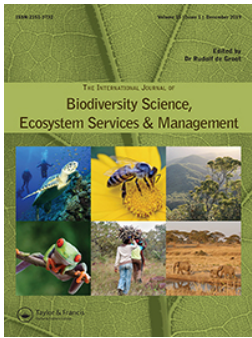
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## Design and implementation of a national ecosystem assessment – insights from the French mountain systems' experience

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### ABSTRACT

The French national ecosystem assessment (NEA), called EFES for « Evaluation nationale des écosystèmes et des services écosystémiques » was launched in 2012 by the Ministry of Environment to comply both with European and national requirements. This paper reports on the design and implementation of the French NEA for high mountain systems, which (i) describes mountain ecological systems, (ii) characterizes the multiple ecosystem services they supply, and (iii) discusses the challenges and options related to sustainable governance of French mountain systems. Results highlighted the disproportional positive contribution of mountains to people's well-being, as well as their vulnerability to several drivers of change such as climate change or modification of agricultural practices. Based on the complete report, non-prescriptive key messages were provided as a summary for decision makers. This assessment was run as a participatory process, led by a core scientific working group and involving experts from academic, institutional and NGO structures. In this paper, we describe and discuss the design and implementation of the French mountain NEA and compare it to other international experiences. We believe our experience can support future NEA processes, in France and in other (inter)national settings.

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### Introduction

Ecosystem assessments are expected to provide policy-relevant information on the relationships between human societies and their natural environment (Ash et al. 2010). International to local levels assessments aim to synthesize the status of ecosystems, their extent and state including their biodiversity, their trends and drivers, as well as the associated ecosystem services (ES) (Maes et al. 2013a). Globally, the Aichi Targets adopted by the Convention on Biological Diversity in 2010 stated the need to preserve or restore ecosystems delivering essential services, in order to 'enhance the benefits to all from biodiversity and ES' (Strategic goal D, CBD 2010). The European Biodiversity Strategy aligns with these objectives, and requires member states 'to map and assess the state of ecosystems and their services in their national territory by 2014' and to 'promote the integration of [economic] values into accounting and reporting systems (...) by 2020' (Action 5 under Target 2, European Commission 2011). Guidance on implementing ecosystem assessments is being provided by the International Science-Policy Platform for Biodiversity and Ecosystem Services IPBES (IPBES 2018) and by the European working group MAES (Maes et al. 2013a). Such international platforms have been carrying out ecosystem assessments at regional to global scales (e.g. Maes et al. 2014) and

identify knowledge gaps that should be addressed to progress in upcoming assessments (Carpenter et al. 2006, 2009). The UK National Ecosystem Assessment has been a front-runner process in Europe, which ended by the publication of both original results and methodologies in 2011 (UK NEA 2011). It has since then been joined by all EU member states, which have in 2018 reached different levels of progress in their national ecosystem assessments (NEAs). Outside Europe, NEAs have also been designed and implemented in the last decade, e.g. in China (Ouyang et al. 2016) or in Japan (JSSA 2010). Importantly, so far approaches differ among countries, with NEA standards depending on political contexts, resources and interests (Schröter et al. 2016). NEAs aim to being credible, legitimate and relevant (Cash et al. 2003), which typically requires i) involving policy-makers and other stakeholders, ii) running the NEA as an open and transparent process, and iii) present finding and knowledge gaps in a policy-relevant but not policy-prescriptive way (IPBES 2018). However, the extent to which NEAs actually achieve these objectives is not thoroughly documented yet (but see Schröter et al. 2016; Allison and Brown 2017).

The French NEA, called EFES for « Evaluation nationale des écosystèmes et des services écosystémiques », was launched in 2012 by the Ministry of Environment to comply both with European and national requirements,

such as the National Strategy for Biodiversity 2011–2020 (Suppl. Mat. 1). Its objectives are to improve knowledge on French biodiversity and on its multiple values, as well as to embed biodiversity and ES in national to local decision making (CGDD 2016). EFESE is led by the Ministry for Environment with a dedicated project team, is supported by a scientific committee, consults diverse stakeholders within a national committee, and builds upon the work of various thematic groups (Kervinio et al. in prep). During the first phase of the program (2012–2018), French ecosystems were assessed considering six main types: agricultural ecosystems, forested ecosystems, wetlands and inland waterbodies, urban ecosystems, marine and coastal ecosystems, high altitude and rocky ecosystems. Each ecosystem type was assessed independently by a core working group led by national experts, following a harmonized report structure based on a unified and co-produced conceptual framework (MEEM 2016).

This paper reports on the design and implementation of the French NEA for mountain systems, with the ambition of sharing key results and knowledge gained, and of reflecting on this experience of science-policy interface. Interested readers are referred to the complete report – in French – for further details on methods and results (Crouzat et al. 2018b). We believe our experience is of interest both at national level to improve future iterations of the NEA process, as well as at international level for supporting other NEA initiatives. We also wish to contribute to the IPBES capacity-building process (IPBES Capacity-building Rolling Plan). Further, we emphasize the originality of the French mountain assessment, which is to our knowledge the only European country where high altitude systems were considered in a dedicated national assessment report. Given the sensitivity of mountains to global and local changes, it appears critical to pay special attention to these fragile ecosystems that deliver ecosystem benefits to people far beyond their borders (Grêt-Regamey et al. 2012; Palomo 2017; Klein et al. 2019; Schirpke et al. 2019b).

## Methods

The objectives of the French mountain NEA were (i) to describe mountain ecological systems, their trends and the specificities of their functioning, (ii) to characterize the multiple ES they supply as well as their interrelations, and (iii) to discuss the challenges and options for sustainable environmental management, planning and policies in French mountain systems. The assessment was completed over a 26 months period (September 2016 – November 2018) by a core working group of one senior and two junior scientists with expertise in mountain systems and ES assessment at the Laboratory for Alpine Ecology, Grenoble (LECA – CNRS), hereafter referred to as

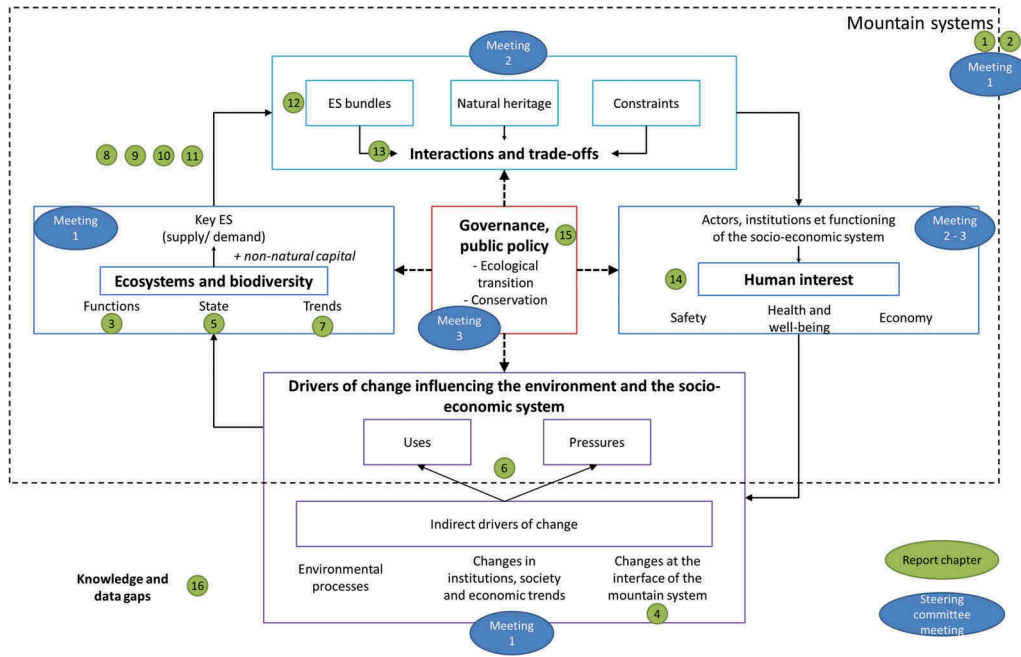
mountain NEA lead authors. The mountain NEA was carried out with limited resources (time, money, skills) and greatly benefitted from the inputs of several experts and stakeholders as described hereafter.

## Framework of the assessment

All ecosystems assessments carried out in EFESE followed the national conceptual framework (MEEM 2016) and a common 16 chapter structure. The conceptual framework's main strengths are its incorporation of multiple values, namely intrinsic, instrumental and relational values (Pascual et al. 2017a), and its emphasis on trade-offs and interactions among ES (Kervinio et al. in prep). Central to EFESE's framework are governance and public policies, given the primary goal of producing relevant results for improved policy and management of environmental resources (Figure 1).

## General organization

Based on the Ministry of the Environment's tender, mountain NEA lead authors were responsible for coordinating and writing the 16 chapters of the report. Lead authors' main background in environmental sciences partly explains the quantitative focus on the supply side of ES, a choice which also aligns with national requirements and with data availability. The ES demand and governance aspects of the mountain social-ecological system were also assessed, although with a qualitative perspective. External experts with thematic expertise were asked for specific complements on individual chapters (e.g. hydrology experts for sections related to regulation of water quality and flows). In-depth review of the chapters was conducted in two steps. First, a 'mountain steering committee' ensured the robustness and relevance of the report by commenting on each chapter. This committee was composed of 15 experts from academia ( $n = 6$ ), public institutions ( $n = 4$ ) and non-governmental organizations ( $n = 5$ ) interested in the sustainable management of French mountain systems. Experts attended three joint meetings over the assessment period, and participated remotely in the review process of the written chapters. Their varied backgrounds helped covering both biophysical, demand and governance aspects in the mountain assessment, although pure social expertise remained a minority (natural science:  $n = 5$ ; social science,  $n = 3$ ; science-decision interface,  $n = 7$ ). Second, the national scientific committee conducted the statutory formal review designed in EFESE to increase the validity of findings and to harmonize reports among working groups at national scale. Mountain NEA lead authors addressed all written comments until final validation by the EFESE scientific committee. Such a review process, incorporating both technical and policy perspectives, has been proposed as a crucial step to validate results and favor



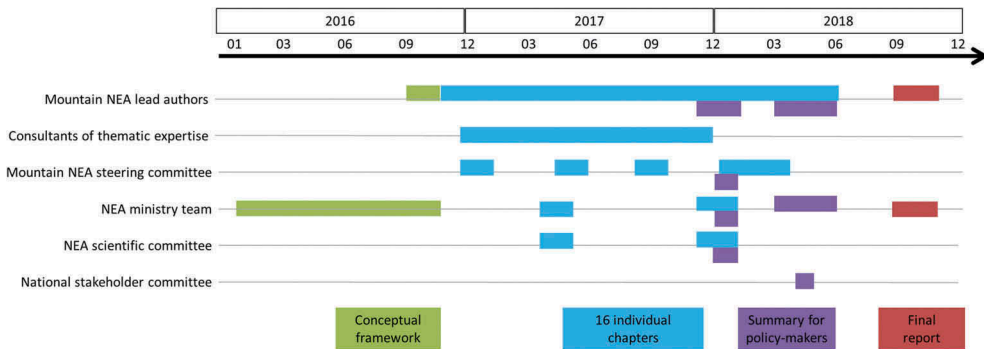
**Figure 1.** Mountain NEA conceptual framework, based on the national guidelines. The general methodology and main findings were discussed with the Mountain steering committee as indicated by the blue circles. The different items of the framework are addressed by the chapters as indicated by the green circles.

their uptake by decision makers (Wilson et al. 2014; Allison and Brown 2017). Following the stabilization of the final report, key messages for decision makers were written by the lead authors in interaction with the Ministry team, providing a four-page summary for policy-makers (MTES 2019, Suppl. Mat 1). Non-prescriptive key messages, along with uncertainty terms, were reviewed and validated at national level after review and discussion with the national stakeholder committee. The final consolidated report was released by the French ministry in November 2018 (Figure 2). Lastly, a short consultation was addressed to the experts of the mountain committee to gather their feedbacks on their perceived roles and on the results of the mountain NEA (not included in Figure 2). This short survey was conducted in February 2019 with the 15 experts involved in the mountain committee to elicit their experience on the participatory process and the value of the mountain NEA for their own objectives. Briefly,

the survey consisted in a closed email questionnaire where experts were asked to reflect on their initial motivation, their role and satisfaction about the process, the assessment’s outputs and their usefulness, and the potential contribution to the science-policy interface, i.e. process outcomes.

**Geographic scope**

There is no unified definition of what can be considered a mountain ecosystem neither in France nor globally (Price et al. 2019). Defining the precise object of concern in the mountain NEA required creating an ad-hoc perimeter. According to the context, existing definitions can account for vegetation, slope, altitude and/or duration of the snow cover, and will either keep a biophysical delineation or stick to administrative boundaries at municipal or department (NUTS3) levels. Mainly, such definitions can be found in the



**Figure 2.** Contributions through time to the mountain NEA. Lines represent the contribution of the different groups while colours refer to the different steps of the process addressed.

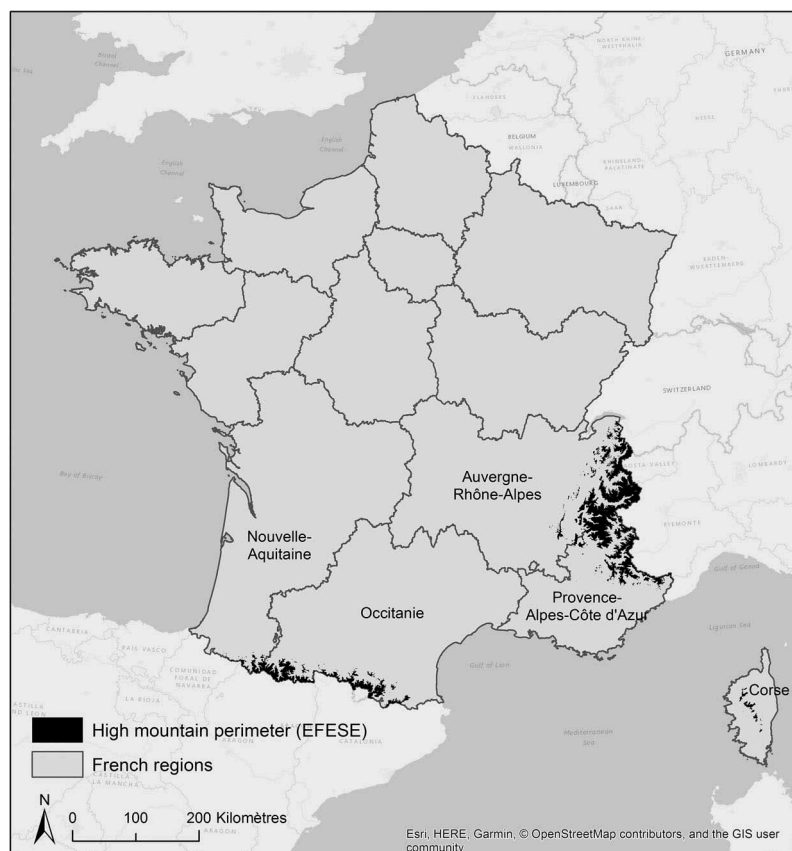
scientific literature, e.g. the geobiological alpine model (Ozenda 2002), in legal documents, such as the French Mountain Law (RF 2016), or in treaties coordinated by non-governmental NGOs, as for the European perimeter of the Alpine Convention (PSAC 1991). In the context of the French NEA, an additional constraint was to avoid overlapping with perimeters considered by other working groups, in order to prevent double-counting of ES values. Following initial tests and advice from the mountain committee, we implemented a four-step method relying on biophysical and land cover criteria. First, based on 100\*100 m DEM, we excluded all areas with altitude lower than 1000 m, and kept montane to nival bioclimatic belts only, as defined by the Global Mountain Biodiversity Assessment (Körner et al. 2011). Second, we used remote sensing images on snow cover for the last decade, and kept only areas with more than 15 days of snow cover per year, at least seven out of 10 years (MODIS NDSI data, resolution 500\*500 m). Third, we used Corine Land Cover 2012 data to exclude land covers accounted for by other working groups, in particular dense forests and crops, and kept categories representative of (semi-)open subalpine to nival environments. The treeline constituted the main lower altitude boundary of our study perimeter. Finally, a fourth

step filtered out remaining patches of less than 10 hectares.

Following this contextual EFESE definition, high altitude ecosystems cover around 2% of mainland France, accounting for around 11 300 km<sup>2</sup> (Figure 3). They are distributed between 1001 and 4810 meters at Mont-Blanc summit, and they include three mountain ranges: the Alps (73%), the Pyrenees (25%) and Corsica (2%).

### Selection of ES and assessment methodology

In the context of the French mountain NEA, ES were primarily assessed in biophysical terms to inform about ecosystems supply capacity. A total of 11 ES selected with the mountain committee as a compromise between relevance to management issues and feasibility within the scope of the assessment were assessed thoroughly quantitatively or qualitatively based on a combination of modeling, mapping and literature review; three additional ES were addressed briefly without detailed investigation due to lack of resources (Table 1). Methods included use of existing data, production of original research, knowledge synthesis and expert consultation. When possible, a spatially explicit approach was favored to describe the distribution of ES values at national scale. Consistent with previous NEAs in Europe (Schröter et al.



**Figure 3.** Geographic scope of high altitude mountains in the French NEA. Names of the regions (NUTS 2 level) concerned by the perimeter are showed (Pyrenees mountain range in Nouvelle-Aquitaine and Occitanie, Alps mountain range in Auvergne-Rhône-Alpes and Provence-Alpes-Côte d'Azur, and Corse mountain range in Corse). We remind the contextual definition of the perimeter for this exercise in absence of unified agreement.

**Table 1.** Ecosystem services considered in the French mountain national ecosystem assessment.

		Treatment		
		Quantitative	Qualitative	Light
Goods	Fodder production	x		
	Wild plants	x	x	
Regulating ES	Global climate regulation (carbon stocks)		x	
	Hydrological regulation	x	x	
	Soil erosion control	x		
	Protection against natural hazards		x	
Cultural ES	Outdoor recreation	x		
	Landscape beauty	x	x	
	Hunting		x	
	Research			x
Natural heritage	Iconic species	x	x	
	Iconic landscapes	x		
	Geographic designation			x
	Inspiration for art and literature			x

2016), to illustrate possible options for improvement in a later iteration of the NEA, we included zooms on case-studies where advanced methods allowed a more precise description of ES status, even though applied over restricted extents. Main beneficiaries were identified for each ES. The mountain committee contributed to the assessment by providing information on relevant projects or literature to integrate, and also by offering their general expertise on mountain social-ecological systems in France, collected during the three committee meetings held over the assessment period.

## Results

Results of an ecosystem assessment are as much contained by the written report as by the social interactions that led to or follow its publication (Allison and Brown 2017). We hereafter comment briefly on the main NEA results, and then expand on the characteristics of the French mountain NEA and their consequences for an uptake of the results for decision making.

### *The French mountain NEA provides integrated synthetic results on ES and trends*

High altitude ecosystems host an exceptional biodiversity linked to their complex topography and geological patterns, to climatic constraints and to historical trajectories, in particular related to glaciations and historical land use trajectories (Körner 2004; Antonelli et al. 2018), and French mountains are no exception to this. Reporting

under Article 17 of the Habitats Directive (period 2007–2012) underlines the overall good conservation status for the habitats of community interest encompassed in the French mountain NEA perimeter (MNHN 2013). However, French mountains are significantly impacted by combined drivers of change, with particularly significant effects of climate change, of local changes in agropastoral practises and of tourism development (Table 2). These mountain systems contribute goods and ES to multiple local and distant beneficiaries. They are highly multifunctional areas that supply high levels of ES despite small surfaces (2%) at national scale (Table 3).

Through their supply of essential goods, ES and natural heritage to people, mountains contribute to human health and well-being (Körner and Ohsawa 2005; Grêt-Regamey et al. 2012). However, the scientific literature still falls short in making such contributions explicit (Pires et al. 2018). As recognized by environmental psychology theories for several decades (e.g. Divers 1984; Kaplan and Kaplan 1989), nature experience in French mountains deeply and positively impacts psychological functioning. But the characterization of specific impacts of mountain ES and biodiversity on the health and well-being of populations still needs further work (but see, e.g. Wartmann and Purves 2018; Bieling et al. 2014 for linkages between mountain landscapes and well-being in Europe). A dedicated session with our mountain steering committee provided us with expert-based assessment of the links between ES and attributes of well-being (Figure 4 for an example).

**Table 2.** Synthetic results of the French mountain national ecosystem assessment. Prevalence and impacts of drivers of change on different high altitude ecosystems, and related trends.

		Drivers of change								Trend	
		Climate change	Fragmentation and destruction of habitats	Agricultural practises	Recreation practises	Development of renewable energy	Invasive species	Pollutions	Over exploitation of biological resources		Public policy
Confidence level		***	***	***	***	**	*	*	*	**	
High altitude mountain systems	Natural grasslands and pastures	***	***	***	**	*	*	**	**	***	↘
	Moors and shrublands	***	*	**	*	*	*	*	*	**	↗
	Transitional woodland/open forest	***	*	***	*	*	*	*	*	*	↗
	Sparsely vegetated areas and rocks	***	**	*	**	*	*	*	*	*	→
	Wetlands	***	***	**	**	***	*	***	*	***	↘
	Glaciers and permanent snow	***	*	*	**	*	*	**	*	***	↘

<b>Confidence</b>	***	High	**	Medium	*	Low
<b>Supply</b>	***	High	**	Medium	*	Low
<b>Evolution</b>	↗	Increasing	↘	Decreasing	→	Stable

**Table 3.** Synthetic results of the French mountain national ecosystem assessment. Ecosystem Service supply capacity depending on main habitat types, associated trends and confidence level. Compared to the list of ecosystem types in Table 2, glaciers are not included here their services are overwhelmingly supplied by their abiotic fraction.

Category	Variable	Supply					Trend	Confidence level
		Natural grasslands and pastures	Moors and shrublands	Transitional woodland/open forest	Sparsely vegetated areas and rocks	Wetlands		
Goods	Fodder production	***	*	**	*	**	↗↘	***
	Picking of wild plants	**	**	*	**	*	↗↘	*
Regulating ES	Global climate regulation (carbon stocks)	***	**	**	*	***	↗	**
	Hydrological regulation	*	**	*	*	***	→	*
	Soil erosion control	**	**	**	*	**	↗	***
	Protection against natural hazards	**	**	**	*	*	↗	**
Cultural ES	Outdoor recreation	***	**	*	***	**	↗	***
	Landscape beauty	***					↘	***
	Hunting	**	*	**	*	*	↘	*
	Research							
Natural heritage	Iconic species	***	*	**	***	**	↘	***
	Iconic landscapes	***					↘	***
	Geographic designation							
	Inspiration for art and literature							

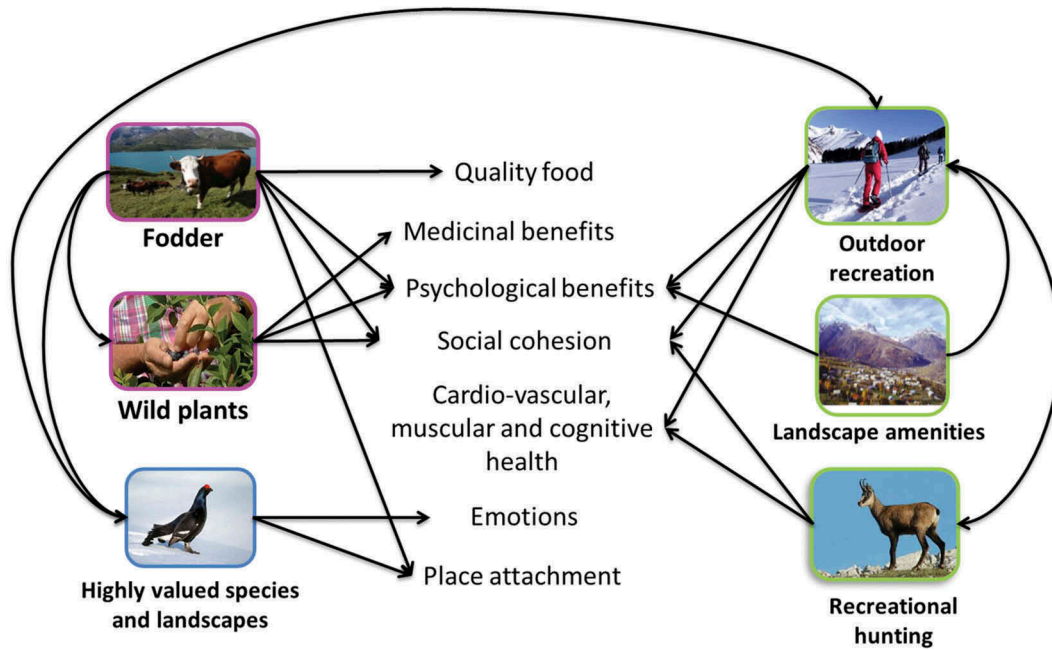
<b>Supply / Confidence</b>	***	High	**	Medium	*	Low
<b>Evolution trend</b>	↗	Increasing	↘	Decreasing	→	Heterogeneous or Stable

Results from the French mountain NEA were synthesized as key messages for decision makers, a now well accepted, and even expected, format of the communication strategy (Allison and Brown 2017; key messages from the mountain NEA available as Supplementary Material 1).

**The French mountain NEA proposes options for sustainable development**

Ensuring a sustainable mountain development remains a challenge at global scale (Wymann von Dach et al. 2016). The French mountain NEA highlights that to





**Figure 4.** Expert-based relationships between ES supplied by mountain systems and health and well-being benefits for local and distant populations.

sustain the supply of goods and ES and to protect natural heritage over the long term, connections over (large) temporal and spatial scales need to be considered (Klein et al. 2019), a necessity captured under French nature protection legislation under the concept of ‘ecological solidarity’ (Mathevet et al. 2016). Among others, this holds true between sources of pressures and locations of their effects, for example, climate change, and between ES supply and demand, where mountains provide disproportionate amounts of ES to remote beneficiaries (Klein et al. 2019). Our mountain committee experts insisted that locally this would imply considering and strengthening the spatial, environmental and economic complementarities among municipalities that ensure the diversity of e.g. agricultural and tourism activities. This need has for instance been revealed by social network analyses of the mountain tourism sector in Switzerland, showing how more connected and modular stakeholder networks promote social resilience (Luthe and Wyss 2016). At regional and national levels, interactions between mountains on the one hand and valleys and distant regions on the other hand need to be considered when analyzing supply, flow and demand of ecosystem services and their biophysical and socio-economic drivers (Schirpke et al. 2019a, 2019b). In France and other European countries, urban populations benefit from mountain ES like provision of quality food, clean water or recreation and tourism, creating a downward ES flow from mountains to valleys. At the same time, the policy mix and economic markets, which are mostly regulated out of mountain perimeters and exert a high influence on mountain landscapes and livelihoods, exert an upward influence from valleys to mountains (van der Sluis et al. 2018), a feature common to many developed and

developing mountain regions (Klein et al. 2019). During the third mountain committee meeting, specifically focused on governance aspects, committee members shared their expertise on how the profuse and intricate set of existing land planning and regional development instruments can support socio-economic and environmental sustainability by implementing and regulating these dependencies. They insisted on the need of better considering cumulated impacts of human activities on environmental resources (Huber et al. 2013; Brunner and Grêt-Regamey 2016), a major gap in current governance. Engaging local and regional stakeholders in participatory processes, e.g. based on participatory scenario-planning, is a way to co-design future pathways to sustainability (e.g. Kohler et al. 2017; Lavorel et al. 2019; Vannier et al. 2019a).

### **The French mountain NEA is a broad and shallow MAES-like assessment**

The French mountain NEA covers a wide range of topics, as revealed by the diverse set of ES or of drivers of change considered. It provides a cross-sectoral, integrated analysis based on individual results assembled for the purpose of the report, favoring a spatially explicit approach when possible. The mountain NEA mostly focused on producing key messages at national or massif level, transferring generic insights about the links between mountain ecosystems, human-well-being and governance through scales. In the complete report, local zooms, informed with higher accuracy through more complex methodologies or additional data, showcase potential improvements for quantitative assessment still out of reach at national level. For instance, regarding the ES of

climate regulation by carbon sequestration, the report illustrated how a tiered approach (Grêt-Regamey et al. 2015) could help fill current knowledge gaps. At the coarsest level, aggregated references for carbon sequestration in different ecosystems are provided by a dedicated national assessment (CGDD 2019). Trait-based models of Gross Primary Production across French mountain ranges provide a first appraisal of spatial heterogeneity in climate regulation supply capacity (tier 2), while an example of dynamic mechanistic modelling (tier 3) was provided for the Hauts-Plateaux du Vercors reserve. Based on these characteristics and following the classification of NEAs proposed by Haines-Young et al. (2008), the French mountain NEA can be described as i) broad in thematic scope (compared to narrow-targeted assessments) and ii) shallow in empirical detail (compared to deep high-resolution assessments). The French mountain NEA strongly relates to the requirements of the EU Biodiversity Strategy on Mapping and Assessment of Ecosystems and their Services (MAES) (Maes et al. 2013a). Compared to other European experiences, this brings it closest to the Flemish regional ecosystem assessment (Jacobs et al. 2016). Both assessments propose a ‘holistic analysis of the conditions, trends, and scenarios of biodiversity and ES’, echoing the Millennium Ecosystem Assessment (MA 2005), but further, add a ‘spatially explicit biophysical quantification and valuation of ES for the whole area’ as characterized by Schröter et al. (2016). According to these authors, previous European NEAs lacked the spatial dimension (e.g. the UK or Spanish NEAs) or the wide scope of MAES-like NEAs (e.g. the Norwegian or Finnish NEAs).

### **Assessing participation in the steering committee of the French mountain NEA**

Five participants provided detailed responses to the survey addressed to the mountain steering committee, while three considered that they were unable to do so because of their incomplete participation and replied with general written comments. The other half of the steering committee did not answer. The statements presented hereafter are therefore not results of statistical significance. Experts reported that their initial interest for integrating the committee related mostly i) to the dissemination of knowledge and experiences towards governance arenas and ii) to their interest for knowledge acquisition and synthesis. The participatory process itself was overall well perceived, although not all members could attend the three meetings due to schedule incompatibilities. Experts stated that the report’s results and key messages for decision makers were overall of satisfying quality, and e.g. that they could usefully influence land planners or policymakers regarding the sustainable use of mountain environmental resources in a context of climate change. However, experts highlighted that the results reached

within the short timeframe of the assessment would deserve further work, in particular in relation with the above-stated knowledge and conceptual gaps which were co-identified during the third meeting. Experts were appreciative of the intended iterative nature of the NEA, and their suggestions should support future-focused studies on priority gaps such as specific issues relating to France’s overseas mountain areas. In spite of the overall positive assessment of outputs, concerns were expressed regarding the need to extend the assessment over a longer period and to further tailor results in an appropriate way for decision making at national or more local scales.

### **Dissemination and policy impacts**

The dissemination strategy of broad and shallow NEAs needs to be carefully planned to reach a wide audience and avoid short-lived impacts (Haines-Young et al. 2008). Recent experiences from NEAs stress the importance of planning the communication and dissemination strategy since the early phases of the process to ensure that the right messages are communicated to the relevant audience via appropriate time and channels (Allison and Brown 2017). In particular, the time just following reports’ publication is pinpointed as particularly favorable to support decision makers with readily available information. At this stage, the French mountain NEA has been shared with national-level policymakers through the Ministry for the Environment using electronic media (the NEA’s dedicated platform, the Ministry’s and the National Biodiversity Foundation’s broadcasts) and dissemination events such as the annual NEA symposium attended by a diversity of national-level stakeholders and policy-makers. The National Biodiversity Foundation edited a 2-page summary for the broad public, and the Ministry edited an English language version published to coincide with the IPBES seventh Plenary meeting (Paris, May 2019). While meeting the European MAES and international IPBES agendas, the timing of the release of findings was not targeted specifically regarding the national political agenda, despite advices on how to increase political uptake of results such as by Wilson et al. (2014). However, it appears difficult in practice to align with both international and national political momentums. In particular, the 1985 French Mountain Law, which recognizes the specificities of mountain areas through a legal framework, was revised in 2016, i.e. before the mountain NEA was ready; nevertheless we believe our assessment could have contributed relevant results for the revision and still holds important information for its local to regional implementation (Figure 2). We ensured institutional dissemination through the online publication of summaries of the main messages (e.g. Lavorel and Crouzat 2019) which have been broadly spread in communication by nature NGOs (e.g. IUCN) and lay web sites. It has been

anticipated that the IPBES platform could further support the development and dissemination of NEA's knowledge and methods, and to some extent facilitate use of their results through scales (Wilson et al. 2014).

Adaptive policy cycles have been described as going successively through the stages of i) problem framing and policy formulation, ii) adoption and implementation, and iii) monitoring and evaluation (Daily et al. 2009; Maes et al. 2018). Knowledge produced and synthesized in the French mountain NEA primarily contributes to the first stage. To achieve policy change and contribute to the next two stages, additional dimensions should be targeted, which go beyond the scope of a NEA: for instance, co-designing with mountain stakeholders and managers ways to practically integrate biodiversity and ecosystem services issues into decision making or building capacity to bridge the gap between individual and collective interests (Allison and Brown 2017). As a salient example our results for the Ecrins National Park were used directly by the park's managers for a successful application to IUCN green list of protected areas.

Yet, it is currently too early to analyze the impacts of the French mountain NEA process and its policy effectiveness (Posner et al. 2016), but such an analysis will be essential if NEAs are to continue engaging non-state actors and targeting social and environmental sustainability (Alcamo 2017). As positive points for achieving policy impacts, the mountain NEA benefits from a conducive policy environment, the NEA being commissioned and funded by the French government, and from the inclusion of stakeholders throughout the process. Of particular interest is that participation in the mountain NEA process might reinforce a 'community of practice' (Blicharska and Hilding-Rydevik 2018) concerned by the possible futures of French mountain ecosystems and their inhabitants. This community starts with the structures engaged in the mountain committee and the national stakeholder committee, but our experts repeated their wish for this community to expand through dissemination of the report's results and dedicated facilitation processes such as transdisciplinary seminars or dissemination to audiences as diverse as elected representatives, planners and entrepreneurs, protected area managers, NGOs and the general public. Already the close links with the expert committee have strengthened networks between assessment authors and mountain decision makers: opportunities for collaboration have arisen and interactions in other arenas foster continuing exchanges and mutual consideration as resources for advice or e.g. data exchange.

## Discussion

To date, the French mountain NEA experience reported in this paper offers a unique policy-motivated, comprehensive analysis of status and trends of mountain ecosystems and ES at national scale. The assessment

considered multiple values (Pascual et al. 2017a), although with more information available on intrinsic and instrumental values than on relational ones. We consider this first mountain NEA report as a baseline laying the ground for many improvements, in particular as discussed below with respect to accounting for interfaces and flows, to addressing current knowledge gaps and to making uncertainty levels more explicit.

### Accounting for interfaces

Interfaces between main ecosystem types vary through time and space, due to combined effects of drivers of change (Briner et al. 2013). For instance, the ad-hoc definition of mountain systems in the French NEA considered the treeline limit, which at high altitude distinguishes dense forest covers from (semi-) open areas, as lower boundary. This limit results both from biophysical limitations to tree growth and from historical land management (Ozenda 2002). Changes in global conditions and in local management practices impact the location of this treeline, with a current upward trend referred to as a greening or encroachment trend in the literature (Carlson et al. 2014, 2017). Therefore, the perimeter of what is considered as mountain in the French NEA will change over time. Further, interactions among ecosystem types occur both directly within the mountain perimeter itself where specific habitats form a diverse mosaic, but also at distance as mentioned in the Results section. Table 4 summarizes interactions connecting mountain systems to main ecosystem types considered in the French NEA. No in-depth treatment of flows across ecosystem interfaces has yet been coordinated at national level, although some were considered within each of the assessments for individual ecosystem types. Salient future science-policy exercises such as IPBES and NEAs will need increased attention to transitional areas, interfaces and teleconnections, as ES flows and governance know no contextual boundaries related to practicalities of the assessment or administrative delimitations (López-Hoffman et al. 2010; Pascual et al. 2017b).

### Knowledge gaps and uncertainties

Coordinating the mountain NEA revealed knowledge and data gaps at national scale, along with resource limitations for using existing data, e.g. for quantifying ES benefits. The second point at least could be easily addressed in further iterations of the NEA. Regarding biophysical data, we lacked particularly spatial distributions of habitats and species, and as noted in other assessments, ultimately we provide limited information on the role of biodiversity per se (Jacobs et al. 2016). Habitat maps at fine spatial resolution should be increasingly available in the next decade at national scale (Touroult et al. 2017), allowing for improved biophysical ES quantification. Consistent

**Table 4.** Main flows at the interface of mountain systems. Flows are considered with main ecosystem types accounted for in the French national ecosystem assessment at national level.

	Flows →	← Flows	
High altitude mountains	Water flows (depending on flow direction, underground, anthropic infrastructures ...)		Wetlands and waterbodies
	<ul style="list-style-type: none"> <li>• Flow of hydro-energy</li> <li>• Physical flows related to natural hazards (stones, avalanches)</li> </ul>	<ul style="list-style-type: none"> <li>• Flow of people attracted by recreation activities</li> <li>• Flow of pressures: artificialisation, periurbanisation, pollutions, colonization by generalist species</li> <li>• Flows of pressure to reduce natural hazards (vulnerability)</li> </ul>	Urban ecosystems
	<ul style="list-style-type: none"> <li>• Physical flows related to natural hazards (stones, avalanches)</li> <li>• Species flows (ex.: wild ungulates)</li> </ul>	<ul style="list-style-type: none"> <li>• Limitation of physical flows related to natural hazards</li> <li>• Flow of tree species (limit of the tree line)</li> <li>• Species flows (ex.: wild ungulates, galliformes)</li> </ul>	Forest ecosystems
	<ul style="list-style-type: none"> <li>• Physical flows related to natural hazards (stones, avalanches)</li> <li>• Species flows (ex.: large predators)</li> </ul>	<ul style="list-style-type: none"> <li>• Limitation of physical flows related to natural hazards</li> <li>• Flows of domestic cattle (relation alpine pasture/farm system)</li> <li>• Flows of atmospheric pollutants (nitrogen in particular)</li> </ul>	Agricultural ecosystems

with mountain regions globally (Klein et al. 2019), data availability also remains limited at fine spatial resolution for some abiotic parameters including mountain soil parameters or climate data such as snow cover distribution (Bormann et al. 2018). Such data are often inputs for downscaled models of ES values in complex and heterogeneous mountain environments. Rapid recent progress in mountain climate downscaling, along with considerable efforts in developing climate services that deliver such state-of-the-art data for science and decision will resolve some of these limitations in the near future (Durand et al. 2009). Inputs from remote sensing technologies, cross-validated by field data, could also improve fine-scale ES mapping and open the way for comparable iterations of analyses in the future (Ayanu et al. 2012; de Araujo Barbosa et al. 2015; Dedieu et al. 2016). Regarding the inclusion of socio-economic variables in the mountain NEA, we were again limited by either scarcity of data at national scale (e.g. spatial distribution of mountain sport practices) or with difficulties to incorporate them in the timeframe of the assessment (e.g. characteristics of pastoral activities in alpine pastures). Finally, as recommendations for future NEA implementations, we highlight the need to further consider: i) French overseas territories and their original tropical and subantarctic ecosystems, ii) the roles of ES, biodiversity and nature for human wellbeing, physical and mental health (Marselle et al. 2019), and iii) future tipping points that might induce regime shifts, three aspects that the duration of the NEA did not allow.

The international standard of IPBES focuses the assessment of uncertainty on i) the level of scientific agreement and ii) the quantity and quality of evidence. To increase transparency on the scientific robustness of our main findings and on their potential use for policy (Crouzat et al. 2018a), key messages for decision makers were labelled by mountain NEA lead authors according to the degree of scientific consensus ('well established' or 'partly established'). The French NEA (Kervinio et al. in prep) adds to these two dimensions

the level of stakeholder agreement on key messages ('under discussion' or 'accepted'), which provides crucial information for policymakers regarding the acceptability of potential governance measures and also perhaps regarding the educational efforts required to ensure their actual implementation. In the case of the mountain NEA, stakeholder consensus on key messages was high, following slight redrafting of key messages during the discussion with the national stakeholder committee. The qualitative rating of scientific consensus would definitely not replace a dedicated uncertainty assessment, which was beyond our means despite its relevance (e.g. Schulp et al. 2014) and we acknowledge this as a limit of the French mountain NEA report. Our priority for mapping ES biophysical values was motivated by European (Maes et al. 2015) and national objectives (CGDD 2016), and our positive experiences at local to regional scales (Lavorel et al. 2011; Crouzat et al. 2015; Vannier et al. 2019b) in spite of known limitations of such outputs in the context of national assessments (Jacobs et al. 2016). Among these, cumulated uncertainties arising from the aggregation of individual results for analyses of ES trade-offs and bundles were not quantified. These are methodologically complex because they combine qualitative and quantitative, sometime spatial, information. Also, although the mountain committee provided qualitative validation and feedback, future communication of results and deliberation with regional decision-makers will contribute to increasing the robustness and acceptability of our conclusions.

### The assessment's governance structure

The French NEA aligns with IPBES recommendations regarding inclusion of experts of various backgrounds that can represent diverse stakeholder groups (Timpte et al. 2018). Although challenging, the participatory dimension of environmental assessments at national or broader scales is seen as an innovation supporting the integration of a plurality of knowledge as well as improving legitimacy and effectiveness in governance

(Oubenal et al. 2017). The mountain NEA experience described here relied on an inter- and transdisciplinary process, through the iterative interactions with the mountain expert committee, the national scientific committee and the national ministry team on the one hand and also through a one-time consultation with the national stakeholder committee on the other hand. Although names of these committees vary among countries, other NEAs in e.g. UK, Portugal or Japan, showed similar governance structures. Wilson et al. (2014) describe these structures as including ‘i) a diverse range of stakeholders which represent the community at large and can provide information about user needs, as well as ii) technical expertise to ensure the assessment process is fair and balanced and can provide advice on complex or contentious issues’. Establishing such governance structure conditions the perceived legitimacy and credibility of NEA results, and thereby their possible policy uptake (Wilson et al. 2014). The rationale for engagement in a participatory science-policy interface is for the mountain NEA to act as a boundary organization with an even representation of knowledge systems and values towards mountain systems (Morin et al. 2017). We note that, as with other international (e.g. IPBES) and national ecosystem assessments, the process was top-down with objectives, a conceptual framework and an implementation plan from the Ministry for Environment rather than being co-produced with national or regional stakeholders and experts. Schröter et al. (2016) also noted this governmental mandate for several European NEAs. Ultimately, the whole process seeks to influence policy at national or regional scales. In this regard, the fair balance between types of structures (academia, public institutions and non-governmental organizations) and between competences (tourism, planning, biodiversity ...) in the mountain expert committee goes in the right direction, although we acknowledge the limited dimension of our participatory process compared to IPBES’s standards (see Timpte et al. 2018 for a detailed description of epistemological backgrounds, gender and geographic origins of IPBES experts).

### Next steps

A broad and shallow assessment such as the French mountain NEA can be considered a promising step towards a broad and deep assessment, which would provide a more comprehensive evaluation by producing and combining novel knowledge at local to national scales. To reach this objective, an incremental process would be required, so as to foster thematic improvements of high policy relevance from the initial NEA, or so-called ‘advanced scoping studies’ (Haines-Young et al. 2008; Schröter et al. 2016). More specific questions could be formulated and addressed, e.g. regarding a subset of ES or some quantification

methods for assessment (Dunn and Laing 2017; Maes et al. 2018). For instance, one member of the mountain steering committee reported that to reinforce the science-policy interface, follow-ups of the mountain NEA should propose methodological support on how to minimize negative impacts on ecosystems and biodiversity in land planning, which was not explicitly addressed in the first round of the NEA. While actual follow-ups for the mountain NEA are still to be developed, the EFESE ministry team is heading toward this objective of a broad and deep assessment at national level and across biomes. In particular, the currently starting second phase of the NEA aims at: i) providing in the short term focused insights on major environmental issues, ii) developing tools supporting decision making in the context of pilot studies, and iii) in the longer term continue the capacity-building process around the NEA, in particular regarding socio-economic dimensions (<https://www.ecologie-solidaire.gouv.fr/levaluation-francaise-des-ecosystemes-et-des-services-ecosystemiques#e2>).

### Conclusion: the way forward – strengthening the science-policy interface to make impacts

The participatory process of the mountain NEA strengthens the science-policy interface through increased dialogue amongst stakeholders (Dick et al. 2018), including more direct communication of scientists with policy-makers at national scale. From here, how could the science-policy interface develop?

The French mountain NEA holds the threefold objective of (i) describing mountain ecological systems at national scale, (ii) characterizing the multiple inter-related ES they supply, and (iii) discussing options for governing their sustainability. By combining diverse sources of knowledge, both qualitative and quantitative, we aimed to address this request formulated by national policy-makers, and overseen by the Ministry for Environment team. By doing so, we played a role of ‘officers’ at the science-policy interface *sensu* Pielke (2007) (Crouzat et al. 2018a), and produced instrumental knowledge favoring the inclusion of (environmental) science in governance processes. One might question the opportunity in NEAs of leveraging scientific knowledge and data to extend the range of questions and options initially considered by policy-makers in addition to directly addressing the initial mandate. If so, NEA scientists could act as honest brokers, a posture that was presented by a member of the mountain steering committee as ‘the most likely to create interest and action from policy-makers’. A more interactive and iterative science-policy interface could promote such a scientific posture, which could help envisioning alternative options for ‘wicked problems’ in mountain environmental governance (Klein et al. 2019). Overall, the mountain NEA contributes to ‘the process of creating

mountains as objects for governance' (Balsiger and Debarbieux 2015): our scientific inputs strengthen the construction of a political object. In this perspective, the ES concept is seized as a pedagogical tool (Blicharska and Hilding-Rydevik 2018) used to give visibility to values and priorities previously not explicitly discussed in land planning and governance. Finally, which standards should be targeted to ensure the transfer from knowledge to action in the science-policy interface in the context of NEAs? To develop scientific uptakes in policy, one might question (i) the credibility of information source for the targeted audience (academic or local knowledge, models used, robustness of results ...), (ii) the relevance of the information provided regarding the political agenda (level of detail, target audience, strategic use of scientific knowledge ...), and (iii) the legitimacy of the assessment, depending on the transparency of the process and on the involvement of varied stakeholder groups throughout the process (Wilson et al. 2014; Berghöfer et al. 2016). Based on feedbacks from decision makers, four criteria are proposed by Dunn and Laing (2017), expanding on this well-known 'credibility, relevance and legitimacy' tryptic from Cash et al. (2003): scientific inputs should be accessible, comprehensive, timely and applicable in order to achieve policy impact. Overall, producing knowledge fulfilling all these criteria appears highly challenging (Berghöfer et al. 2016). Our mountain NEA experience confirmed that an adequate science-policy interface for sustainable environmental governance requires time, significant dedicated resources as well as the shared will to go beyond a linear model of science (Crouzat et al. 2018a). An interactive long-term dialogue amongst stakeholders at the science-policy interface (Young et al. 2014) would more effectively create the opportunity to interweave different knowledge and value systems for addressing co-designed questions (Tengö et al. 2017; Pascual et al. 2017a), thereby attaining the policy impacts ambitions of NEAs and the IPBES for supporting progress towards sustainability challenges.

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