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A review of ES knowledge use in spatial planning

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ABSTRACT

Despite the great progress made in ES (ecosystem service) science, the integration of ES into spatial planning remains below expectations. The science-policy/practice gap in ES application impedes the transformation toward sustainable spatial planning. In this review, we draw on the perspective from the science-policy interface to examine the use of ES knowledge in spatial planning. From the science perspective, we find that the usability of ES science has improved in recent years, although the evidence base used in planning remains incomplete; from the policy perspective, there is a lack of research on the way policymakers demand knowledge and their logic of action. Issues of power and politics are under-explored; given that the ES community advocates knowledge co-production as a significant merit of the ES approach, this is both surprising and worrying because of the multiple risks inherent in participatory processes. ES research should attend to these aspects to realize greater integration and policy effects in spatial planning.

1. Introduction

The ongoing global biodiversity loss and widespread ecosystem degradation pose a major threat to environmental sustainability. The ecosystem service (ES) framework claims to provide an integrated and holistic approach to recognize and evaluate the interdependence of human wellbeing and ecosystems' health, and therefore, to account better for nature's value in decision-making. Great advances have been made in ES science since (Costanza et al., 1997) and (Daily, 1997) seminal work, particularly in ES valuation, assessment, mapping, and modelling (Costanza et al., 2017)); international initiatives, such as MES and TEEB (MEA, 2005; TEEB, 2010), that have brought ES to the forefront of policymaking, and the IPBES (2012), the explicit goal of which is to promote integrating ES into the policy agenda. Much is expected of ES to inform policy and practice to achieve urgently-needed transformations toward sustainability (Daily et al., 2009).

There are two recurring aspects of the ES approach that (Fish, 2011) believes can be harnessed creatively to improve environmental decision-making: the first is to "think holistically" about human activities in ES provision and human wellbeing; the second is to recognize wider stakeholders and their values, needs, and priorities, etc. Spatial planning is regarded as a critical venue to integrate ES knowledge (de Groot et al., 2010; Gómez-Baggethun and Barton, 2013; Haaren et al., 2016). Apart from the two aspects above, many identify ES's added value for spatial planning in terms of various tools and instruments, such as mapping and modelling, which can serve as decision-support tools and provide a better evidence base for planning (Cortinovis and Geneletti, 2018; Cortinovis et al., 2021; Woodruff and BenDor, 2016).

Nevertheless, the degree to which ES is integrated into policy and practice remains below expectations (Di Marino et al., 2019). Overall, ES's inclusion in US and EU policy is limited and largely unbinding (Schleyer et al., 2019); when the ES approach is adopted, it is a struggle to exert real influence on the ground because of institutional inertia (Kvalvik et al., 2020). Even in fields such as urban planning and landscape planning, which have a long tradition of valuing certain types of ES (e.g., recreation, landscape aesthetics, runoff mitigation, etc.), ES frameworks have not yet been embraced fully after more than a decade of advocacy (Cortinovis and Geneletti, 2018; Rall et al., 2015; Thompson et al., 2019).

The problem of slow integration and poor outcomes gives rise to critical reflection on the use of scientific knowledge in environmental decision-making. Some ascribe it to the science-policy gap that is a pervasive challenge in sustainability science and governance and emphasize that a more effective science-policy interface should be

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created to improve mainstreaming ES in policy (Bertuol-Garcia et al., 2018; Perrings et al., 2011; Watson, 2005). Using the criteria of usable science acknowledged widely, i.e., credibility, saliency, and legitimacy (Cash et al., 2003), some have suggested that the ES research community should establish knowledge systems that can improve ES science usability in these aspects simultaneously (Posner et al., 2016). Moreover, empirical studies on integrating ES into planning recognize institutional dynamics, such as legacy effects or institutional inertia, e.g., established professional and administrative rules and norms, as major constraints to the full application of the ES approach (Saarikoski et al., 2018; Waylen et al., 2015). Several comprehensive reviews have been performed on the way ES evaluation informs decision-making (Laurans et al., 2013), ES application in spatial planning practice (Longato et al., 2021), urban ecosystem services research (Haase et al., 2014), decision-support tools for ES (Grêt-Regamey et al., 2017), the blind spots in ES assessments research (Lautenbach et al., 2019), and the lessons learned from ES implementation in urban planning (Grunewald et al., 2021). Although these previous reviews have provided valuable insights on ES knowledge use already, we think a review that explicitly focuses on ES knowledge use in spatial planning practice and links to the same issue in sustainability science is still missing. In response to this gap in the literature, in conducting this review, we seek to understand why, compared to the great number of outputs the ES research community has generated to inform spatial planning, ES continues to have a limited effect on policy and practice. We begin by reviewing different models of science-policy relations and the concept of the science-policy interface, to draw an analytical framework for the following section, in which we turn to the literature on integrating ES into spatial planning and policy. We analyze modes of ES knowledge use, the ES evidence base, and barriers to integration. Through this literature review, we wish to identify areas that more research need to be dedicated to, if more effective science-policy interface is to be built for ES to better inform spatial planning.

2. Theoretical framework

2.1. *Different models of the science-policy practice*

Academic debate on science-policy interactions has experienced a gradual shift from linear models to more co-productive ones (Dilling and Lemos, 2011; Kirchhoff et al., 2013; Maas et al., 2022). This shift is a reflection of changes in ontological and epistemological understandings of scientific knowledge and its relation to society (Nutley et al., 2007, p. 110), as the positivist view of knowledge as a static, tangible product produced merely by scientists is being challenged increasingly by interpretivism and constructivism's view of knowledge production as a dynamic and interactive process and necessitates learning, sharing, collaboration, and exploration on the part of multiple stakeholders (so-called co-production) (Carmen et al., 2018).

Maas et al. (2022) developed a conceptual framework which considered three components of science-policy practice: repertoires, competencies, and context (Table 1). Repertoires can be seen as a conception of the link between knowledge production and use. They combined the three main types of repertoires (supplying, bridging, and facilitating) in knowledge brokering identified by (Turnhout et al., 2013) with three logics of useable knowledge in decision-making articulated by (Dewulf et al., 2020) (Table 2).

Both in the supplying and bridging repertoire, knowledge production and knowledge use are viewed as separate activities and thus conform to linear models of science-policy practice (albeit to different extents) (Turnhout et al., 2013). While supplying repertoire presumes the decision-making to be a rational process, determined only by science-based options and their consequences (logic of consequentiality); bridging repertoire emphasizes intensive interactions between knowledge producers and users to make sure the knowledge product is in line with the institutional and cultural rules of decision-making (logic of appropriateness). In the facilitating repertoire, the boundary between knowledge production and knowledge use is blurred. Knowledge is held by all actors involved in the science-policy practice and thus no distinction can be made between active producers and passive recipients (Turnhout et al., 2013). This repertoire follows the logic of meaningfulness in decision-making, which is not a politically neutral process but a constant struggle over different value dimensions of a problem (Dewulf et al., 2020). The outcomes of this repertoire are not necessarily recognized as knowledge in a traditional sense (Maas et al., 2022).

Table 1
The linear and co-productive models of science-policy practice.

		Linear	Co-productive
Repertoire (How is one expected to operate in the science-policy practice?)	**Knowledge brokering**	Supplying, bridging	Facilitating
	Logics of decision-making	Consequentiality and appropriateness	Meaning
Competencies (what makes practitioners able to perform the practice well?)		Boundary work & stage management e.g., the ability to communicate and translate between science and policy, build and maintain high-trust relations, enable iterative exchanges, etc.	Co-productive agility, e.g., the ability to engage in co-productive processes, understand different viewpoints, be sensitive and responsive to changing objectives or new knowledge, and constructively navigate the tensions in such settings.
Context (in what ways do context factors stabilize the practice?)		Expert-driven policy context in which institutional and spatial configuration promotes separate domains of science and politics	Normatively drive policy context in which institutional and spatial configuration promotes conjunction of science and politics

Resources: Maas et al. (2022); Turnhout et al. (2013), and Dewulf et al. (2020).

Table 2
Three repertoires of knowledge brokering.

	Supplying	Bridging	Facilitating
Knowledge brokering	Provide policymakers with knowledge produced by experts.	Answer questions policymakers have with relevant knowledge produced by experts.	Enable policymakers and experts to collaborate to co-produce more-than-knowledge.
Logic of decision-making	Logic of consequentiality. Decisions are based on their expected consequences.	Logic of appropriateness. Decisions are based on knowledge that is produced in line with particular institutional and cultural rules.	Logic of meaningfulness. Decisions are based on what is meaningful to decision-makers.

Resources: Turnhout et al. (2013) and Maas et al. (2022).

2.2. *Different modes of knowledge use*

Measuring knowledge use and its impact are full of fuzziness and challenge (Arnott and Lemos, 2021). "Use" itself can have multiple meanings, of which (Rich, 1997) distinguished four main types: 1) knowledge is received and read (use); 2) knowledge is identified as having potential value but without a specific purpose yet (utility); 3) knowledge has contributed to a decision (influence), and 4) knowledge has led to clear and concrete action (outcome). As to the way knowledge gets used in practice, several modes of use can be seen from the literature, as presented in Table 3; nevertheless, a typology of use defined by (Weiss, 1979) which distinguished conceptual, instrumental and strategic modes of use, is widely accepted.

2.3. Science-policy interface

To promote evidence-informed decision-making, the fuzzy boundary between science and policy needs to be effectively managed. Science-policy interface (SPI), as defined by (Van den Hove, 2007), refers to "social processes which encompass relations between scientists and other actors in the policy process, and which allow for exchanges, co-evolution and joint construction of knowledge with the aim of enriching decision-making"(p.807). SPI could range from large and highly formalized institutions to informal discussions. In their seminal work, (Cash et al., 2003) suggest that knowledge institutions that seek to effectively harness knowledge for sustainability should manage boundaries between knowledge and action in ways that simultaneously enhance the salience, credibility, and legitimacy of the information they produce. These criteria are then widely adopted as usable science (Clark et al., 2016). However, as noted by Sarrki et al. (2014), critical trade-offs among three criteria always exists and can be very intensive at times.

The main reason we choose to use science-policy interface as a conceptual perspective is that ES knowledge production and spatial planning practice both are arenas that necessitate intensive interactions and co-productive activities (Braat and De Groot, 2012; Carmen et al., 2018), which means that both science and policy should be scrutinized for low integration and impact of knowledge; most importantly, we see this perspective as productive because it allows us to situate the discussion of knowledge co-production and use in the broader academic debate in sustainability science and other fields such as science and technology studies.

3. Review method

As noted by papers on the methodology of literature review, what we have done here is a traditional narrative review (Snyder, 2019; Xiao and Watson, 2019). We think this type of review serves the purpose of exploring the links between different concepts and is appropriate for the topic of knowledge use which can be implicit in its nature. Our approach does not aim to cover all literature available, but not miss significant pieces of work on this topic.

For the selection of literature, we searched the Scopus scientific database (www.scopus.com) for peer-reviewed articles accessed on Oct 15th, 2022. we developed search queries with keywords and synonyms for three main categories: this first category is ecosystem service(s), the second is actions associated with using knowledge in practice (e.g., application, implementation, operationalization, integration, policy, practice), the third is spatial planning as the focus of policy arena (take into consideration different sectors and regulatory contexts of planning, e.g., spatial, landscape, urban, marine, terrestrial, land use, planning). After that, we screened papers by reading titles and abstracts to determine whether or not they focused on knowledge use and should be included in subsequent analyses. Then we read the full-texts of selected papers and made the final decision to include or exclude. In this process, we continued to include papers that were identified from reference lists. The final review is based on our critical reading and understanding of the full texts of these included papers.

4. Results

4.1. An overview of ES research through the perspective of SPI

Drawing on the three attributes of usable science put forward by (Cash et al., 2003) and widely accepted in sustainability science (Dilling & Lemos 2011, (Kirchhoff et al., 2013), Cash et al., 2016), we begin by looking at to what extent ES research meets these criteria. ES science is "… complicated and high in epistemic uncertainty, rapidly developing and still contested" (Jordan and Russel, 2014), which may undermine its credibility. In addition, a lack of saliency in ES research is mentioned frequently (Laurans et al., 2013; Martinez-Harms et al., 2015; Longato et al., 2021) previous reviews all indicated that only a small fraction of ES research has considered its relevance to policy. Drawing on multiple examples of ES knowledge use in practice, Olander et al. (2017) synthesized the principal reasons why ES assessments and valuations the research community has produced do not meet decision-makers' needs. It is noted that a lack of saliency is often accompanied by a lack of legitimacy or credibility. For example, ES information is not salient when 1) presented as pure ecological or biophysical outcomes that are not associated with social values or is unable to present transparent and unambiguous linkages between ecosystem processes, services, and value; 2) unable to estimate changes in ES values that arise from changes in policy or management; 3) unable to capture location-specific factors that determine value fully; 4) unable to address ES directly relevant to organizational decision-making contexts; 5) models' accuracy, uncertainty, and reliability are unknown, and 6) practitioners and policy-makers lack the expertise, data, or capacity to navigate technical problems involved in models and assessments. Mandle et al. (2021) pointed out further that little ES research accounts for the full value chain (processes-functions-services-benefits-values, as reflected in the ES cascade model (Potschin et al., 2016) and the distribution of ES among beneficiaries, which undermines its relevance to policy. They suggest that more inclusive, collaborative, and demand-determined approaches are imperative to improve ES's relevance to decision-making (Mandle et al., 2021). Suggestions have been made about problem-oriented ES assessments (Förster et al., 2015), user-friendly and accessible models (Levrel et al., 2017; Olander et al., 2017), and the combination of top-down valuation with bottom-up deliberative approaches (Kieslich and Salles, 2021), to name a few.

As can be seen, the usability framework mainly took the standing of scientists providing evidence to decision-makers, less attention is paid to how such evidence is perceived and used in real practice contexts. Research from the policy and practice side has received relatively late and undue attention. In the establishment of IPBES, (Briggs and Knight, 2011) recognized the "…intermingling of scientific knowledge, political judgement, and practical considerations", and the "turbulent, not linear"

Table 3
Different modes of knowledge in literature.

Mode of use	Definition
Conceptual /enlightenment	Knowledge incorporates new ideas, broadens and deepens understanding, shapes attitudes and ways of thinking, allows people to develop new beliefs and values, and opens a window of opportunity for policy change.
Strategic/tactical	Knowledge is used to support and promote a specific intervention or policy option, or justify beliefs and values held previously.
Instrumental/ technical	Knowledge flows from scientists to rational decision-makers who make observable decisions on technical grounds; knowledge provides information for decision-making directly and helps choose appropriate instruments to achieve an objective.
Other modes are mentioned in the literature with finer distinctions from the modes above.	
Political/ symbolic	Compelled to use certain types of knowledge by some external imperative, such as high authority. This is often confused with strategic use.
Coproduction	Knowledge use and generation result from a two-way process of interaction between generators and users. Sometimes this is combined with conceptual use.
Non-use	Knowledge is rejected consciously.

nature of the science-policy interface. There is naivety in ES research about the conditions in which knowledge use does or does not occur, by whom, and for what purposes (Russel et al., 2016). Drawing on Latour's actor-network theory, Collins et al. (2009) revealed that an assessment method's (ecological footprint in this case) technical credibility was assembled through the network of actors around it; knowledge brokers, stakeholders with their respective interests, and agenda framings largely determine to what extent an assessment will be accepted, and the robustness of knowledge per se plays only a small part in this process. Similarly, by comparing ES with former environmental assessments in the UK and Ireland, Cowell and Lennon (2014) revealed the role of institutional contexts and policy venues in determining whether new knowledge could go through the obligatory passing point. By investigating ES's integration into spatial planning cases in OpenNESS projects, Saarikoski et al. (2018) identified social and institutional contexts as major constraints on knowledge use, including competing interests and political agendas, scientific disputes, professional norms and competencies, and lack of vertical and horizontal integration. They also found factors that facilitate use, such as more transparent and participatory methods, social capital, policy champions, and synergies between ES and human wellbeing.

4.2. Different modes of ES knowledge use

The field of ES knowledge use was addressed systematically first in the 2014 Environment and Planning C theme issue, in which seven papers introduced the literature on knowledge production and use into ES research and discussed several policy venues of knowledge use. Land use/spatial planning is the theme of two papers (Cowell and Lennon, 2014; McKenzie et al., 2014) on which later discourses are largely based. The general model (Weiss, 1979) put forward, which includes conceptual, instrumental, and strategic use, is adopted by the ES research community (Jordan and Russel, 2014; McKenzie et al., 2014; Russel et al., 2016). Table 4 presents the terms, definitions, and some examples of different modes of knowledge use mentioned in the literature.

4.2.1. Conceptual use

ES knowledge's conceptual use is reflected primarily in the way it promotes a comprehensive and systematic understanding of nature's value to society. The concept's initial appeal to economic valuation fits well with market failure or externality in economics, by considering ecosystems as "*underestimated in traditional economic analysis and decision-making*" (UKNEA, 2014). Hence, the ES concept is deemed to change the dichotomy between economy and environment and point to a win-win solution (de Groot et al., 2010). Moreover, ES can serve as a boundary object with the potential to promote interdisciplinary and collaborative research and practice; develop common issues, standards, and methods (Steger et al., 2018); integrate different stakeholders' values and preferences; promote cross-sectoral, cross-scale spatial decision-making (Fürst et al., 2014), allow easier communication to the public, and raise environmental awareness in society. Hence, conceptual use is the basis of integrating ES into planning. Many studies have indicated that the ES framework can raise stakeholders' awareness, as evidenced by (Dick et al., 2018) in their case studies of stakeholders' attitudes toward the ES concept, and (Forkink, 2017) in cognitive surveys. Stakeholders may find different aspects of ES appealing, which implies the importance of conceptual framing in communicating ES with various groups (Opdam et al., 2015). Language adapted appropriately to the specific audience can be a more effective argument-making device to mobilize capacities and share resources (Carmen et al., 2018). For example, alternative terms, such as nature's value or contributions, green infrastructure, and nature-based solutions, can convey the ES concept better to promote participation and collaboration.

Table 4
Three modes of ES knowledge use and examples.

Mode of use	Examples
Conceptual	Communicate with and convince stakeholders and policymakers of human dependence on nature; change their choices and preferences
Strategic	Conceive development scenarios, communicate trade-offs associated with scenarios, and mediate conflicts among stakeholders.
Instrumental	ES mapping, quantification, modelling, cold-spot and hot-spot identification, conservation schemes; Payment for ES scheme design; knowledge use in CBA or MCDA

4.2.2. Instrumental use

Instrumental use takes place when "… scientists use relevant technical tools to help rational decision-makers". It is also the way knowledge is expected to be used in a rational linear model, where science serves as an impartial arbiter of policy choices, such as in making choices among alternative schemes, or in policy design and intervention programs. To some extent, the ES community has inherited technical rationality and always takes instrumental use wrongly as the only sign that knowledge is being used (Russel et al., 2016). There was strong advocacy for instrumental use in the early stage of ES research, as can be seen in the way TEEB emphasized mapping, quantification, and evaluation (TEEB, 2010). Instrumental use is also the use researched most. ES has proven to be an effective approach to synthesizing information from multiple sources (Longato et al., 2021). For example, ES mapping can inform green infrastructure sites or conservation schemes by identifying ES cold-spots or hot-spots, supply-demand mismatches, etc. (Zhang and Ramirez, 2019; Li et al., 2020; Meerow, 2019; Van Oorschot et al., 2021) conducted recent studies in which ES mapping was used to identify GI priority areas based on service deficiency, population vulnerability, or maximized synergistic effects. It is not surprising that these types of use constitute the majority of research on ES for spatial planning, because as a new output, spatial maps are highly consistent with information used in everyday planning norms and processes.

4.2.3. Strategic use

The strategic mode justifies the merit of specific choices or is used to mediate conflicts among stakeholders to obtain their support for specific policies (McKenzie et al., 2014; Saarikoski et al., 2018). Sometimes, strategic use is confused easily with political or symbolic use in which knowledge is used only to justify previously-held positions and is generally seen as a misuse of knowledge (see Section 2.2). However, McKenzie et al. (2014)argued that strategic use can be a positive way to enhance the ES agenda's viability, and in this way, it allows ES to extend across scientific boundaries into complex policy contexts. Moreover, as spatial planning practice involves trade-offs inherently, strategic use represents a stage in which conflicts of interests and values among multiple stakeholders are addressed. Planning at the local scale is where tradeoffs manifest in concrete decisions, such as choosing among alternative development scenarios that involve conflicts of interest (Saarikoski et al., 2018). Therefore, strategic use features a hybrid process, including the use of participatory methods and decision support tools to form reasonable, legal, and enforceable spatial strategies.

As McKenzie et al. (2014) indicated, a specific mode of use often dominates at a particular stage of decision-making. They presented this as a near-linear process. Conceptual use is common in the early stages when stakeholders work together to generate knowledge about different development scenarios and their effects on ES supply, gain an understanding of ES, and change their beliefs and values. Strategic and instrumental use occur repeatedly in the middle and later stages of decision-making, during which interest groups and decision-makers interact, and ES knowledge is used to support specific decisions and promote planning implementation. (Ruckelshaus et al., 2015) synthesized similar pathways in the way ES affects decision-making, in which knowledge dissemination and consensus-building (conceptual use) are followed by more strategic and instrumental use. However, such a conceptualization of knowledge use and the production process is too simplistic considering that in the use process, new knowledge is constructed through co-productive activities (Russel et al., 2016; Waylen and Young, 2014) and different types of knowledge use always occur simultaneously (Haines-Young and Potschin, 2014).

4.3. ES knowledge use in spatial plans, policy, and practice

For the past decade, a significant body of literature has explored the way ES is integrated into policy documents and among practitioners. The literature often takes two approaches. Qualitative research methods, such as content analysis of related documents and semi-structured interviews with key informants, are used to understand the current status of ES integration and the way administrative and professional actors perceive the opportunities, risks, and barriers of mainstreaming ES. For each approach, we include academic papers that were published between 2010 and 2021, as listed in Table 5, and synthesize their key findings in the sections below.

4.3.1. "Explicit" and "Implicit" use of ES

ES knowledge may be used "explicitly" or "implicitly". Implicit ES knowledge is found widely in spatial plans, particularly in those related to habitat and recreational benefits that urban green spaces provide (Davies et al., 2015), and can be dated back a century (Wilkinson et al., 2013). Although many benefits of ecosystems were recognized before the ES concept was introduced formally, they have been assessed and managed through traditional sector-based frameworks (e.g., recreation, aesthetics, water supply, and runoff mitigation) (Rall et al., 2015). Nevertheless, it is uncertain whether explicit use equals higher integration. "Explicit use" may indicate the conscious application of the ES concept (Schubert et al., 2018), while "implicit use" is only a general understanding of nature's value. Hansen et al. (2015) indicated that certain elements in the ES toolbox, particularly various kinds of economic evaluation, have been used for quite a long time, albeit only for a limited set of ESs. Explicit adoption of the ES framework tends to consider more service types and includes both service supply and demand in the evidence base (Woodruff and BenDor, 2016). Planners may feel that the actual integration of ES already exists, even if there is no explicit reference to ES terms (Mascarenhas et al., 2014). The "explicit use" of ES terms may be "window dressing", and merely have an indirect and non-binding influence on policy and practice (Schleyer et al., 2015; Thompson et al., 2019), while comprehensive and mandatory incorporation of the ES approach is quite different.

4.3.2. Modes of knowledge use

The conceptual mode of use dominates. ES is useful in communicating among sectors, departments and between the government and the public. Instrumental use, such as evaluation, mapping, and quantification, appears only in a few plans, or exists only for a small set of ESs. Strategic use is rare: ES-related goals are not expressed clearly in the vision statement of plans, and trade-offs are either not recognized or not discussed. Information about service beneficiaries and possible trade-offs are absent even in plans that adopt the ES framework explicitly (Woodruff and BenDor, 2016); cultural or recreational services are exceptions because of planners' familiarity with them and the readily available models, techniques, and indicators (Cortinovis and Geneletti, 2018; Di Marino et al., 2019). Most practitioners' understanding of the ES concept is limited to the scope of green space planning (Davies et al., 2015); moreover, current skills related to green space can hinder more comprehensive ES applications: Planners hesitated to use new ES knowledge compared to the traditional green space planning approach when formulating urban and regional development policies (Di Marino et al., 2019; Mascarenhas et al., 2014; Rinne and Primmer, 2016))

4.3.3. The quality of the ES evidence base

An expanded evidence base is deemed the additional value of the ES approach. Van Wensem et al. (2017) proposed a minimum set of criteria to assess the extent to which the ES approach is applied, i.e., whether all

Table 5
Papers published between 2010 and 2021 that explored ES knowledge use in spatial plans, policy and practice.

Authors	Type of planning	Country/region
Research method: Content analysis of spatial plans and policy.		
(Wilkinson et al., 2013)	Strategic spatial plans	Melbourne, Australia; Stockholm, Sweden
(Kabisch, 2015)	Urban and landscape plans	Berlin, German
(Mascarenhas et al., 2015)	Spatial planning and SEA	EU and Portugal
(Rall et al., 2015)	Urban planning	New York and Berlin
(Hansen et al., 2015)	Comprehensive planning, green space planning; environmental planning	Berlin, New York, Salzburg, Seattle, and Stockholm
(Schleyer et al., 2015)	EU policy related to ES	EU
(Woodruff and BenDor, 2016)	Comprehensive planning	Damascus, Cincinnati, US
(Bezák et al., 2017)	National, regional and urban planning, and SEA	Slovakia
(Nordin et al., 2017)	Comprehensive planning, green planning, and sectorial planning	Six Swedish municipalities
(Noe et al., 2017)	Conservation planning	Minnesota, US
(Cortinovis and Geneletti, 2018)	Urban plans	22 Italian cities
(Lam and Conway, 2018)	Land use plans	10 municipalities in Ontario, Canada
(Schubert et al., 2018)	Comprehensive planning	Municipality of Malmö, Sweden
(Di Marino et al., 2019)	Land use planning	Helsinki-Uusimaa Region, and the City of Järvenpää, Finland
(Thompson et al., 2019)	Municipal plans	19 Canadian municipalities
(Kvalvik et al., 2020)	Coastal zone planning	Norwegian coastal municipalities
(Khoshkar et al., 2020)	Municipal comprehensive plans	231 municipalities in Sweden
Research method: Surveys, interviews and focus groups with related stakeholders.		
(Niemelä et al., 2010)	Semi-structured interviews with 24 professionals involved in land-use planning and environmental administration in Southern and Central Finland.	
(Hauck et al., 2013)	Focus group discussions (with EU level Directorate); regional survey with key stakeholders from multiple sectors related to ES, to representatives of organized groups such as companies, NGOs, state agencies, and planning associations, covering the regional scale.	
(Albert et al., 2014)	Semi-structured interviews and a web-based survey with German landscape and regional planners.	
(Mascarenhas et al., 2014)	Questionnaire survey with practitioners and decision-makers from Portuguese regional spatial planning authorities.	
(Kabisch, 2015)	Face-to-face interviews with eight stakeholders involved in urban green space planning and development processes.	
(Rall et al., 2015)	Semi-structured key informant interviews with 18 stakeholders involved in green space planning, management and research—10 from New York City and 8 from Berlin, primarily from city administrative departments, but also including important stakeholders from ecological research, public-private initiatives, and nonprofit organizations.	
(Bremer et al., 2015)	Semi-structured interviews, with 26 terrestrial and 27 marine natural resource managers, respectively, representing a range of government, non-profit, and private landowners and managers in Hawai'i.	
(Beery et al., 2016)	Individual interviews with 36 municipal stakeholders.	
(Kaczorowska et al., 2016)	20 semi-structured interviews and a stakeholder workshop. Participants came from the public, private, and civic sectors and play a role in urban development in the Stockholm region.	
(Schubert et al., 2018)	36 individual interviews with municipal stakeholders in seven coastal municipalities. The participants were municipal civil servants and politicians who are (or have been) involved in ES planning.	
(Di Marino et al., 2019)	Semi-structured interviews with four official planning practitioners in the Helsinki-Uusimaa Region (from the Environmental, Housing and Tourism Divisions), and three	

(continued on next page)

Table 5 (*continued*)

Research method: Content analysis of spatial plans and policy.		
Authors	Type of planning	Country/region
	city planners from the Land Use Division of the City of Järvenpää, respectively.	
(Khoshkar et al., 2020)		Individual dialogue meetings with the three municipalities, each with 2–6 municipal practitioners (individuals with professional backgrounds as municipal planners, ecologists, and environmental and climate strategists attended).
(Grunewald et al., 2021)	Semi-structured interviews with urban planning practitioners in ten cities/city-regions of seven European countries.	

relevant service types, the full chain of service production, and all stakeholders affected are included.

A limited set of ESs is covered in spatial plans and policy. In most cities and regions, ES types covered in spatial plans include habitats for species, cultural services (such as landscape aesthetics and recreational benefits), some regulating services (air, storm water, and climate regulation), and provisioning services (fresh water, food supply) (Cortinovis and Geneletti, 2018; Hansen et al., 2015; Rall et al., 2015). Soil-related services are mentioned rarely despite their fundamental role in providing service (Teixeira da Silva et al., 2018). This result is consistent with previous reviews on ES assessment research (Haase et al., 2014; Lautenbach et al., 2019) and on decision support tools developed for ES (Grêt-Regamey et al., 2017). ES assessment methods reflect whether multiple dimensions of ES value are considered. Integrated assessments that combine multiple methods are always needed to elicit various stakeholders' values and needs (Bryan et al., 2010), evaluate different service types or satisfy the demands of different decision-making stages (Dunford et al., 2018). In addition, explicit representation of service suppliers and beneficiaries, as well as the spatial and social trade-offs involved in planning alternatives, is the prerequisite for the just distribution of ES (Kabisch, 2015). In this sense, current spatial plans and policy scarcely include a thorough and complete evidence base, and thus, mismatches and trade-offs are not addressed well (Cortinovis and Geneletti, 2018; McPhearson et al., 2014).

4.3.4. *Barriers to further ES integration*

Most studies have highlighted three types of significant barriers to ES integration: lack of knowledge and guidance; lack of data, and institutional barriers. First, we address barriers related to a lack of guidance, resources, and expertise to apply ES. Institutional factors such as established professional practices, norms, and values, are difficult to change rapidly ((Kvalvik et al., 2020; Rinne and Primmer, 2016)). Professional planning associations (such as APA in the US) fail to provide explicit guidance on ES, and practitioners are confused about when the ES concept should be applied in the planning process and what information and tools are needed for decision-making (BenDor et al., 2017; Ronchi, 2021; Woodruff and BenDor, 2016). La Rosa et al. (2019) suggested further that the ES framework should be integrated into planning through formal institutional design, such as reforms in planning laws.

In addition, the availability and accuracy of data may not meet the needs for robust decision-making at finer scales, as most ES data are based on rough land cover maps appropriate for decision-making only at the regional scale (Haase et al., 2014). Further, and most importantly, the cross-sectoral and cross-scale integration and reforms in formal institutions needed to integrate and implement ES will not take place soon. The lack of horizontal and vertical integration in spatial planning and natural resource management today is a major obstacle (Primmer and Furman, 2012; Saarikoski et al., 2018).

Currently, planners report that they obtain access to new ES knowledge largely through best practice projects, and personal interactions with peers and researchers, with minimal input from scientific studies (Albert et al., 2014). At the organizational level, spatial planning sectors should institutionalize learning as a prerequisite for applying ES in decision-making, and manage the boundary between practitioners and scientists more effectively, e.g., through workshops, collaborative projects, and training seminars (Blicharska and Hilding-Rydevik, 2018).

5. Discussion

5.1. *Knowledge use examined through the science-policy interface*

Overall, spatial planning practices have yet to adequately address the complex social reality of ES knowledge use. We have synthesized the deficiencies and challenges in ES knowledge use from the perspective of the science-policy interface, which enables us to understand ES knowledge use from both sides and through their interactions.

From the science side (i.e., the usability of knowledge it provides for decision-making), the criteria of usable science, i.e., credibility, saliency, and legitimacy, are not met fully in ES knowledge. ES's credibility may be compromised because of the high level of uncertainty and oversimplified assumptions in ES mapping and assessment, and practical constraints, such as data availability and accuracy, and resources (time, expertise, and money) needed to produce thorough evidence base (Longato et al., 2021; Laurans et al., 2013). ES knowledge lacks saliency when it is not problem-oriented and demand-determined (Martinez-Harms et al., 2015), which leads to mismatches between the knowledge produced and decision-makers' needs, and scale mismatches between ES assessment and spatial governance. Failing to involve all relevant stakeholders reduces ES knowledge's legitimacy and hinders its implementation and policy outcomes. Posner et al.'s (2016) quantitative analysis showed that overall, high credibility, saliency, and legitimacy tend to increase policy effects, and legitimacy appears to be the most prominent factor in cases in which ES has a greater effect. When considering the way ES knowledge is used, i.e., conceptual, instrumental, or strategic mode of use (Weiss, 1979); (McKenzie et al., 2014)), similar trends have emerged from both research and practice. The conceptual and instrumental modes of use dominate, while strategic use is very rare. This is very surprising, given that one merit of the ES approach is its focus on wider stakeholders' engagement in decision-making. In addition, the ES evidence base used in spatial planning is often incomplete concerning the services types, value dimensions, and affected stakeholders included (Van Wensem et al., 2017).

The scientific robustness (i.e., credibility) of ES assessments has improved in recent studies (Lautenbach et al., 2019); further, guidelines, frameworks, and checklists have been proposed to promote the relevance of ES knowledge to spatial planning decisions (Olander et al., 2017; Rosenthal et al., 2015). For example, (Albert et al., 2016) and (Haaren et al., 2019) incorporated the ES cascade into the DPSIR model used widely in landscape planning; (Woodruff and BenDor, 2016) proposed evaluation criteria to apply the ES framework to four aspects: setting objectives; public participation; factual basis, and policy implementation. Cortinovis and Geneletti (2018) explored the way ES capacity, demand, flow, and benefits can be linked directly to the main variables in urban planning, i.e., the location, type, and scale of urban green infrastructure, as well as the population and infrastructure's spatial distribution and vulnerability. These guidelines are followed increasingly in practice and have improved the evidence base significantly, albeit that certain persistent problems, such as scale mismatches, and off-site effects, have yet to be addressed fully.

Hence, considering the great improvements in ES science in recent years, the problem of its infrequent use and less-than-optimal outcomes can be explained in part from the policy perspective of SPI. There is a paucity of studies on the way policymakers choose to use knowledge or not, under which criteria and for what purpose, with only a few exceptions in individual projects (e.g. (Dick et al., 2018; Grunewald et al., 2021). Most ES research is underpinned inherently by the technical, rational imaginary with assumed decision-makers in mind who demand knowledge to make better policies, as (Jordan and Russel, 2014; Turnpenny et al., 2014) critiqued. We may go further to conclude that existing research is concerned predominantly with the supply side of ES knowledge; little research has explored the way the demand side, such as the logic and processes of policymaking, interacts with knowledge production. The assumed usability of science from scientists' perspective may not be consistent with that from the decision-makers' perspective. Ample lessons can be learned from the broad environmental policy field. For example, Dewulf et al. (2019) distinguished three logics of decision-making, consequentiality (based upon the utilitarian value of knowledge), appropriateness (based upon the institutional theories, the way knowledge fits existing rules and routines), and meaningfulness (based upon sensemaking and interpretation), and explored their implications for policymakers' choice of knowledge use. The study by (Kowalczewska and Behagel, 2019) on Polish environmental policy indicated that science-policy relations (i.e., linear or co-productive model) are shaped by trade-offs between criteria of quality, relevance, conformity, and action orientation, and policymakers' preferences and demands vary greatly in different circumstances. Thus, more research should be dedicated to understanding the decision-making processes and contexts, at individual and multiple institutional levels, that influence perception of ES, willingness and ability to use ES knowledge (Lemos et al., 2012).

The ES approach leaves most of its promises undelivered. Initially seen as a paradigm shift in the way we perceive and manage ecosystems, the integrated, holistic thinking pattern ES promotes confronts critical barriers in real-life policy contexts continuously. ES integration does not occur in an institutional vacuum; rather, established institutions, including sector-based policy and interests, and professional norms and practices, place critical constraints on its operationalization ((Chen et al., 2019; Saarikoski et al., 2018). Lack of coordination and collaboration in cross-sector and multi-level governance is the primary obstacle to integration (Schleyer et al., 2015); moreover, some practitioners are reluctant to embrace new ideas and ways of thinking and working (Cowell and Lennon, 2014) indicated that a favorable combination of institutional settings (support from policy champions and interest groups) and agenda framing allowed new knowledge to go through an obligatory passing point, i.e., to be accepted in formal institutions. Some have suggested that changes in high-level regulatory frameworks can provide a window of opportunity to integrate ES (La Rosa, 2019; Scott et al., 2018). However, the way formal institutional changes affect knowledge use is under-explored (Kvalvik et al., 2020) suggested that institutional inertia is a major barrier to the adoption of new knowledge, and incremental changes, rather than policy replacement, would occur after ES is introduced on top of existing policies.

5.2. Participatory processes and politics of co-production in ES knowledge use

The ES approach is thought to be conducive to participatory processes and broad stakeholder engagement. Decisions related to ES are inherently value judgments (Caceres et al., 2015; Jacobs et al., 2018). Many advocate that ES assessment should follow the knowledge co-production model (Carmen et al., 2018), and integrate stakeholders and their knowledge, values, and preferences actively, rather than transfer knowledge to passive receivers (Dick et al., 2018). In ideal participation, participants have a relevant knowledge base and receive good training; different value dimensions of ES are expressed fully, and different ecological and institutional scales are considered (Fürst et al., 2014); the ES framework is chosen consciously to resonate with participants with different social backgrounds and interests (Opdam et al., 2015). Participatory mapping, such as PGIS and PPGIS, are effective techniques; they may be limited with respect to credibility and representativeness because of limited participation, but can serve as a social learning tool to empower stakeholders and provide a framework for constructive debate (Tusznio et al., 2020). Decision support tools such as scenario development (Arkema et al., 2015; Lerouge et al., 2017) and Multi-Criteria Decision Analysis (Gret-Regamey et al., 2017; Langemeyer et al., 2016) are used often to foster collaborative processes. In a France and Finland land use planning case, (Brunet et al., 2018) demonstrated that ES visualization, storytelling, and gamification can enhance public participation and planning implementation greatly.

Spatial planning needs to resolve the conflict between the competitive demand for limited resources and the uneven distribution of costs and benefits (Geneletti, 2011). The trade-offs are addressed and the strategic mode of use arises in participatory processes (Aryal et al., 2022; Howe et al., 2014; Turkelboom et al., 2018). At the center of participation and trade-off is the knowledge-power dynamic. ES knowledge is political inherently because what is considered knowledge is a result of power relations (Russel et al., 2016). Stakeholders' knowledge "… may not be perceived as equally valid with an implicit hierarchy of knowledge which prioritizes specific knowledge types" (Carmen et al., 2018). Spyra et al. (2018) cautioned against the potential risks in participatory processes when power imbalances exist among social actors and may serve to exclude certain groups. This can be seen in the "my ES" phenomenon, in which influential participants place too much emphasis on ES of their special interest. A case study of 22 spatial planning tradeoffs in the OpenNESS project showed that agenda-setting that influential groups and experts dominated determined what was traded off, but less influential groups often bore the costs of those trade-offs (Turkelboom et al., 2018).

The challenge of addressing the analytic-deliberative relation that (Fish, 2011) pointed out shows no sign of weakening after a decade. It involves issues of power and stakeholders, multidisciplinary research, and politics, and is under-represented in ES research. In our review, we found that the politics of co-production is neither recognized well nor represented fully (Turnhout et al., 2020). Nearly all agree that ES adoption and implementation necessitate the co-production of knowledge; however, some understand it as a technical and procedural issue that can be addressed through the application of user-friendly and inclusive tools ((Levrel et al., 2017)), but these were shown to be insufficient to overcome the implementation gap. As the ES framework aspires to be pluralistic and transdisciplinary, and promote participatory and inclusive decision-making, the lack of research on power and politics in knowledge production and use is worrying (Turnhout et al., 2020). Moreover, some are concerned that the co-productive knowledge model blurs the assumed distinction between knowledge and politics (Turnhout et al., 2013); whether co-production would distort or politicize science, and the way this, in turn, would influence the way decision-makers choose to use knowledge, requires further research (Maas et al., 2022).

6. Conclusion

Research on ES knowledge use in spatial planning has only a decade's history, as the work by authors in the 2014 theme issue in the journal *Environment and Planning C* shows (Dunlop, 2014; Jordan and Russel, 2014; McKenzie et al., 2014; Turnpenny et al., 2014; Waylen and Young, 2014). However, although it is in its infancy, the core framework that these authors put forward, drawing on the rich literature on knowledge production and use, remains insightful. Although the dominant instrumental mode of use has been recognized widely and critiqued, and knowledge co-production is advocated, we see only a few signs of deviation from this track. Indeed, the usability of ES science has improved significantly with respect to its credibility, salience, and legitimacy (Cash et al., 2003; Clark et al., 2016)), which is largely attributable to the refinements of ES assessments and the adoption of more problem-oriented, inclusive approaches. However, challenges in ES knowledge's actual use and its effect on policy and practice remain.

The expected merits of the ES approach for environmental decision-making, such as the holistic thinking about human effects on nature, and the consideration of wider stakeholders' needs and values, as well as various decision support tools (mapping, modelling) it offers for spatial planning, are embodied in the conceptual, strategic, and instrumental modes of knowledge use. The general trend emerged from our review that the instrumental mode of use generates not only the majority of knowledge produced, but is also the mode of use that most ES scientists expect and intend. A natural result of this trend is that undue attention is given to policy contexts and decision-makers and their co-productive role in the processes (Maas et al., 2022) also pointed out that the criteria of science usability adopted widely (i.e., credibility, saliency, and legitimacy) assume a linear model inherently, in which a clear distinction between facts and values, or science and politics, can be made; in doing so, the political dimension of transformations to sustainability is diluted. Our review also reflected the two interrelated aspects that the literature scarcely addresses, i.e., the strategic/political mode of use and unequal power relations in participatory processes. This is the most challenging aspect of ES research, and more generally in sustainability science (Scoones et al., 2020). Existing research on ES knowledge use has not yet been echoed in wider studies on science-practice-society relations, particularly in the field of science and technology studies and political science. Spatial planning, with its rich academic tradition in participatory research, can contribute to this line of research and in turn, benefit from the lessons learned.

As the adverse effects of climate change and ecosystem degradation on human wellbeing have become increasingly clear, countries all around the world are struggling to achieve transformation toward sustainability. Integrating ES into spatial planning is a much-needed effort, and is adopted by some countries, such as China, in the ongoing reform of formal spatial planning institutions (e.g., (Liu and Zhou, 2021; Zhou et al., 2017). This review shows that an effective science-policy interface has not been created. Apart from improving usability from the science side, much effort is needed to understand policymakers' needs and the institutional arrangements that impede knowledge adoption. A potential direction for future research may be how to manage institutional dynamics to promote integrating ES into planning.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Fang Wei reports financial support was provided by Zhejiang Provincial Natural Science Foundation of China (No. LY19E080025).

Data Availability

No data was used for the research described in the article.

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