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Knowledge brokering and boundary work for ecosystem service indicators. An urban case study in Finland

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ABSTRACT

Governing urban green infrastructure is challenging due to the various institutions, interests and values involved in municipal planning, decision-making and management processes. Indicators of urban ecosystem services and green infrastructure may support the development of mutual understanding among municipal authorities and the creation of usable information. In this study, the application of ecosystem services (ES) indicators is approached through knowledge-brokering and boundary work theories. We apply a set of GIS-based ES indicators in a medium-sized Finnish city in a collaborative process with local civil servants in order to provide overarching information on the green infrastructure and to enhance dialogue among civil servants. We present the three phases of the indicator application process (conceptual, instrumental and reflection phases) describe the indicator-based boundary work, and identify factors affecting the process. The results highlight the importance of collaboration and active knowledge brokering in indicator applications, involving a combination of conceptual and methodological expertise on the ES approach with knowledge on local environment and relevant policy and planning issues, as well as iterative reflection throughout the indicator application process. Finally, some critical characteristics of boundary work in applying the ES indicators are proposed.

1. Introduction

Urban green infrastructure, that is the network of multifunctional natural and semi-natural green and blue areas and elements such as parks, tree-lined avenues, green roofs, agricultural land and woodland, wetlands and gardens in urban environments (EEA, 2011), is under pressure as the urban population grows and the anthropogenic pressure on urban ecosystems increases (Seto et al., 2013). At the same time, urban green infrastructure can positively affect residents' wellbeing through the provision of multiple ecosystem services, such as recreation, cushioning of noise, and storm water control (EEA, 2011).

Given the pressure on and importance of urban green infrastructure, deliberative governance has been considered crucial in respect to it, but at the same time it is considered challenging due to the multiple institutions and actors with conflicting interests and agendas (Carmona and Sieh, 2008; Cowell and Lennon, 2014). At local level, for instance, urban green infrastructure governance includes multiple processes ranging from strategic land-use planning covering the whole municipality, to detailed planning of districts and parks, and finally to the practical management of green areas like parks and urban forests. This fragmentation of responsibilities creates tensions and a silo effect whereby communication between municipal departments is fragmented (Holgate, 2007), and hence there is a need for more integrated decision-making frameworks (Smith et al., 2013). For municipal planners and decision-makers it can be challenging to cross the jurisdictional boundaries in administration and the boundary between science and policy. A further challenge is the different geographical and time scales of urban green infrastructure, since there is considerable variation in both the features of green infrastructure, from urban cores to peri-urban areas, and the views on what is desirable or beneficial and to whom (Ernstson et al., 2010; Andersson et al., 2014; Faehnle et al., 2014).

The ecosystem services (ES) approach has received increasing attention both among researchers and land use planners (Cowell and Lennon, 2014; McKenzie et al., 2014) and great expectations have been placed on the ES approach as a means to inform planners and decision-makers about the benefits and values associated with ecosystems (e.g. TEEB, 2011). It has been emphasised that the ES approach can support a broadening of ecosystem preservation, from specific grids of single-purpose land, to wider networks of multi-functional green infrastructure (Borgström and Kistenkas, 2014), and to stimulate the creation of new knowledge and deliberate governance styles (Haines-Young and Potschin, 2014). Given

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the promise of the ES approach, researchers have contributed to the conceptual and technical development of ES indicators that aim to capture states and trends of provisioning, regulating and cultural ES in a policy-relevant manner and form (Müller and Burkhard, 2012). Indicators are well-known communication tools for simplifying and understanding complex systems such as the environment (Turnhout et al., 2007; Müller and Burkhard, 2012). Turnhout (2009: 403) defines ecological indicators as 'science-based instruments that classify nature into different (ecosystem) types, each of which is characterised by specific parameters and references'. To date there are ES indicators scaling from global (see e.g. Serna-Chavez et al., 2014) to continental (e.g. Paracchini et al., 2014), national (e.g. Larondelle and Haase, 2013), regional (e.g. Söderman et al., 2012) and local levels (e.g. Gómez-Baggethun and Barton, 2013; Helfenstein and Kienast, 2014).

ES indicators can act both as a means to link different disciplines, data and actor boundaries, and as a medium for the integration and communication of information between multiple actors in simple language (Schuurman, 2003; Smith et al., 2013). In practice, however, application of ES indicators still is a rather novel approach in land use planning contexts, and it is only recently that studies on the actual use of ES indicators and operationalisation of the ES approach have been published (Primmer and Furman, 2012; Albert et al., 2014). Although indicators have been seen as a promising tool for production and dissemination of policy-relevant knowledge on the status and changes of the ES, they do not alone solve the challenge of knowledge utilisation (Kandziora et al., 2013; Cowell and Lennon, 2014). Earlier research on indicator use suggests that more emphasis should be put on engaging relevant stakeholders in the development and application of indicators (Rinne et al., 2013). Recently Sébastien et al. (2014) have demonstrated that, besides their direct input into policy making, indicators generate influence and a variety of indirect conceptual and political uses. The role of indicators in policy making is dictated more by the characteristics of the information users and policy context than the characteristics and quality of indicators (Sébastien et al., 2014).

In this article, we are interested in the requirements for applying and using ES indicators and the potential of ES indicators to enhance a dialogue between different municipality jurisdictions and actors in the context of urban green infrastructure governance. We study the application of ES indicators from the perspective of knowledge brokering and boundary work theories, which concern of how scientific knowledge can be incorporated into decision-making. Knowledge brokering is a widely used approach for concretising the ways that science-policy interactions can be supported and facilitated by a knowledge broker carrying out boundary work (Michaels, 2009; Ward et al., 2009; Sheate and Partidario, 2010; Ward et al., 2012; Turnhout et al., 2013). At the practical level, knowledge brokering is about active interaction between knowledge producers and users with the aim of guaranteeing that the users have the information they need (McNie, 2007; Michaels, 2009). Boundary work is the practical communication, mediation, facilitation and translation tasks (Gieryn, 1995; Guston, 2001; McNie, 2007 Hoppe and Wesselink, 2014). By focusing on knowledge brokering, boundary work and ES indicators we are particularly interested in:

(1) exploring and discussing what kind of boundary work is needed in the application of ES indicators;
(2) analysing the critical factors relevant to applying the ES indicators in cross-jurisdictional collaboration.

We will first present theoretical concepts and discussions on science-policy interactions and boundary work in relation to the application of ES indicators, which provide the conceptual frame for our analysis. Next, we introduce a Finnish case study where a set of ES indicators were applied, and explain our material and methods. After that we explore and explain how ES indicators were applied in practise from the perspective of boundary work and collaboration, and analyse what were critical factors as well as barriers in applying the ES indicators in the context of urban green infrastructure governance and management.

2. Key concepts: knowledge brokering and boundary objects

2.1. Knowledge brokering

A lot of attention is paid to how scientific knowledge could better be integrated into planning and decision-making processes in order to enhance evidence-base of decisions (Guston, 1999; Cash et al., 2003; Lemos and Morehouse, 2005; Holmes and Clark, 2008; Fazey et al., 2013). It has been stated that the production of salient, credible and legitimate information is not enough for current societal problems and dynamic policy processes and that more emphasis should be put on the knowledge transfer (Cash et al., 2003; Fazey et al., 2013). Knowledge transfer has traditionally been conceptualised as a linear one-way process starting from the researcher and ending with policy officers, civil servants, and decision-makers (Ward et al., 2012). This view has been challenged by interactive and two- or multi-dimensional processes of *knowledge exchange*, which are models that acknowledge knowledge transfer as a dynamic and complex social process incorporating distinct forms of knowledge from multiple sources (Graham et al., 2006; Ward et al., 2012; Fazey et al., 2013). This overarching approach considers and integrates the whole process of knowledge production, dissemination and use as a single entity.

To a researcher, knowledge exchange means taking new roles that strengthen interaction and collaboration with knowledge users and thus supports stronger and multi-directional links between knowledge and action (Turnhout et al., 2013). Michaels (2009) classifies different practical modes of science-policy interactions, as 'knowledge brokering strategies', ranging from linear content dissemination to more interactive and collaborative strategies in which different actors can jointly identify the expertise and knowledge needed or even co-produce the knowledge. Knowledge brokering strategies become concretised with knowledge brokering techniques, i.e. 'boundary work' (Gieryn, 1995; Guston, 2001; Hoppe and Wesselink, 2014). Depending on the context, such as different planning and policy problems or phases of the process, different knowledge brokering strategies (with different intensities and resource requirements) are appropriate. Therefore it is necessary to recognise and acknowledge the knowledge brokering context and tailor the knowledge brokering process accordingly (Ward et al., 2009; Saarela et al., 2015).

In this paper we use the three repertoires of knowledge brokering presented by Turnhout et al. (2013) (see also Ward et al., 2009) as the conceptual frame for our analysis (Table 1). The repertoires, i.e. perspectives and associated knowledge brokering techniques become concrete with the practical boundary work that is associated with each of them. 'Supplying' repertoire focuses on the knowledge system and the supply of relevant expertise or knowledge, but the knowledge production and uses are, however, regarded as separate domains. In the 'bridging' repertoire, the boundary between production and use is considered more dynamic, and the role of the knowledge broker is to link these two and facilitate an interaction. 'Facilitation' is the most resource intensive repertoire, which aims at enhancing real collaboration, co-production of knowledge and capacity building. The boundary between knowledge production and use becomes blurred as the process is framed as a joint effort and user needs are discussed during the process.

Table 1
Knowledge brokering: three repertoires and their aims (Turnhout et al., 2013), examples of techniques (van Kammen et al., 2006; Michaels, 2009; Ward et al., 2009; Sheate and Partidario, 2010; Haug et al., 2011) and associated knowledge brokering strategies (Michaels, 2009).

	Aim	Boundary work	Dominant knowledge brokering strategy
Supplying	To supply expertise, experts or knowledge To find out the problem or research questions To match up relevant experts	Synthesising research: fact sheets, web sites, reviews, assessments, summaries, policy briefs Meetings Knowledge sharing events Introducing people to each other Clarifying knowledge needs Facilitating access to knowledge	Informing Consulting Matchmaking
Bridging	To mediate and interact with the knowledge producers and users To facilitate and support the process	Research-user workshops/forums Internet platforms Interviews Network analysis	Matchmaking Engaging Collaborating
Facilitating	To integrate the knowledge production and use so as to create solutions for the problem in hand To facilitate joint process framing To create an atmosphere of trust	Joint mapping exercises e.g. on goals or policy options Setting up a multi-disciplinary and collaborative advisory group Policy gaming Adaptive co-management Co-production of knowledge Joint fact finding	Engaging Collaborating Building capacity

2.2. ES indicators as boundary objects

Knowledge brokering activities can be institutionalised in ‘boundary organisations’, that is, organisations or individuals mandated to act as intermediaries between knowledge producers and users, facilitating the exchange of knowledge between them (Guston, 2001; Cash et al., 2003; White et al., 2010; Fazey et al., 2013). One of the most often recognised functions of a boundary organisation (or a knowledge broker) is the creation of boundary objects, which can take place in any of the previous-described repertoires. Boundary objects are material or abstract objects that are simultaneously concrete enough to connect different disciplines, facts, knowledge, interest groups and individuals, yet flexible enough to have a meaning on both sides, and stable enough to travel in between and to maintain an identity (Star and Griesemer, 1989; Turnhout, 2009; White et al., 2010; Smith et al., 2013).

Practical examples of boundary objects include scenarios (Girod et al., 2009), simulation models (White et al., 2010) and indicators (Turnhout et al., 2007; Turnhout, 2009). Furthermore, tools based on the GIS (*geographic information systems*) technology ‘have increasingly become the common ground for sharing data across disciplines, or the “glue” which connects large-scale interdisciplinary research’ (DiBiase et al., 2006: vii) and hence they been found to support the development of mutual understanding and communication between different actors in spatial planning (Carsjens and Ligtenberg, 2007). Thus, spatial ES indicators can be regarded as boundary objects in the governance of urban green infrastructure. They can support establishing shared understanding by providing room for joint discussions and by moderating differences (Harvey and Chrisman, 1998). To that end, the indicators need to be unequivocal, but at the same time allow for different considerations and interpretations in different contexts (Turnhout, 2009).

The use of ES indicators in real-world cases is a social process – and the usability of indicators a social achievement – that may require skilled intermediaries who carry out boundary work in between science and practitioners (Turnhout et al., 2007; Turnhout, 2009; Cowell and Lennon, 2014). Meaningful application of the ES indicators needs to be based on collaboration and utilisation of different and appropriate knowledge brokering techniques during the whole application process (Michaels, 2009). We utilise Pregernig's (2000) framework for analysing the factors affecting the application of indicators in real-world processes (see also Sébastien et al., 2014). The use and influence of indicators are explained by three types of factors: (1) the given information (*indicator factors*), (2) the knowledge, experience and attitudes of the receiver (*user factors*), and (3) external context (*policy factors*). *Indicator factors* include the quality of indicators, which generally refers to saliency, credibility and legitimacy. Lists of characteristics and criteria for effective ES indicators point out for example indicators’ ability to convey information at multiple spatial and temporal scales, and according to data availability (Layke, 2009; Layke et al., 2012). *User factors* include an individual level way of thinking and acting, which affects indicator use. *Policy factors* mean the political meta-context within which the indicators are applied. The three factors are interdependent and not mutually exclusive, and the influence of indicators result from the interaction of these factors (Sébastien et al., 2014).

Indicators have also been the subject of more critical perceptions. Turnhout (2009: 410) states that ecological indicators (spatial or non-spatial) appear to be rather fragile boundary objects, as they are ‘able to connect only those social worlds that share common cultural values and preferences, and interpretation and modification of boundary objects can occur only within the limits of these values and preferences’. Spatial ES indicators should not be accepted as neutral boundary objects by definition, as they are strongly tied to their social and institutional context as well as to the values and customs of the actors involved in the process. Traditional maps may also legitimate the dominance of instrumental knowledge and given perceptions, which may lead to excluding different views and values (Smith et al., 2013). Harley (1989) has further described that cartography has ‘internal power’ as a map itself exerts some influence over the world and therefore influences the shaping of their institutional and social context (Smith et al., 2013). Keeping this in mind, ES indicators should be applied carefully both in science-policy processes and in stakeholder outreach (Hauck et al., 2013).

3. Materials and methods

3.1. Background and context

The empirical material for the research was obtained from the EVITA project (*Ecosystem Services and Green Infrastructure in Tampere*), conducted in 2012–2014. The project had two objectives: (1) to provide information on ES and the green infrastructure of the municipality of Tampere for different planning and management purposes, (2) to facilitate dialogue on green areas and ES between municipal departments in order to enhance development of mutual understanding on urban green infrastructure. The project aimed at supporting – along with other more detailed and/or smaller-scale quantitative studies on municipality's green areas – particularly the forthcoming revision of the local master plan of the downtown area. EVITA was planned and conducted as a collaborative project between the municipality of Tampere and the Finnish Environment Institute (SYKE), a government affiliated institute for environmental research. 'The Sustainable Community unit', located in the municipal central administration, funded the project and was responsible for its outputs. SYKE was responsible for the majority of the project activities, such as providing background information on ES, conducting GIS analysis, and facilitating of collaborative events.

Tampere is the third largest city in Finland with about 220,000 inhabitants (Fig. 1). The population of Tampere has been and is growing mainly due to migration from the rural areas to the urban centres (Statistics Finland, 2014), and Tampere is expected to have 57,000 new residents by 2040 (Municipality of Tampere, 2015). There is high demand for new residential areas, which causes pressures to build on green areas. In 2000–2012, approximately 80% of the urban region expansion in Tampere took place on former forest, recreation and areas of sports activities (Tiitu, 2014). Green infrastructure is governed and managed by multiple municipal departments (Table 3).

3.2. Process of ES indicator application in the municipality of Tampere

GIS-based ES indicators were applied to study the green infrastructure and the ES of the municipality of Tampere. Here 'applying' refers to an overarching process including selecting relevant indicators, conducting GIS analysis, and interpreting the results in collaboration with researchers and civil servants. The study was based on an existing ES indicator methodology that was originally developed for land-use planning purposes for Finnish urban regions by SYKE and utilises mainly publicly available GIS data from national and municipal repositories (Söderman et al., 2012). In this case the indicators were applied in wider context (municipal governance of green infrastructure). CICES (The Common International Classification of Ecosystem Services) (Haines-Young and Potschin, 2013) framework, a recent international attempt to support mapping and valuing of ES was selected as an overarching framework for the ES indicators. However, the multi-level CICES classification was considered, by the researchers, too detailed for civil servants not familiar with the ES approach. Therefore, a simplified presentation of the CICES was used to facilitate communication with the civil servants in the beginning when familiarising them with the ES approach. This more general presentation allowed the civil servants and researchers to focus on the ES relevant for urban land use planning and how they could be studied with the ES indicators (Table 2, but see also Table A1 in the appendix for detailed information on the ES indicators). The indicators illustrate mainly the potential supply of ES in the area. Some indicators also take into account the population and illustrate therefore the potential demand for ES. Some indicators describe directly certain ES, whereas others can be considered as proxy indicators that indirectly describe one or more ecosystem services. The GIS analyses of the indicators were carried out on three different scales: inner city, the municipality of Tampere, and the Tampere city region (Fig. 1, Table 2, and Appendix for two graphical illustrations). In addition of the ES indicators, three additional analyses related to the drivers of change (such as land use change and traffic) were carried out.

The municipality of Tampere was selected as the focus of our research as the municipal administration expressed a strong interest both in analysing the green infrastructure with the novel ES approach and ES indicators, and involving different administrative sectors in the governance of green infrastructure. Researchers had an interest in drawing lessons from applying the ES indicators in practice and in analysing boundary work in this context. These objectives were pursued by designing a participatory and collaborative project structure. The role of a knowledge broker in this case was played by the team of social-science-oriented SYKE researchers. Two GIS experts joined the process and carried out the GIS analyses for the ES indicators. They also participated in facilitating the joint discussions. Their role can best be described as 'participatory knowledge producers' who worked in close collaboration with the practitioners in a process where the boundary between knowledge production and use became blurred (Turnhout et al., 2013).

The indicator application process was prepared in co-operation with researchers and civil servants and proceeded in three consecutive phases: *conceptual*, *instrumental*, and *reflection phases* (Fig. 2). The phases gave structure to the actual project, and also framed our analysis of boundary work. The *conceptual phase* lasted for 6 months and was aimed at introducing and familiarising the civil servants with the ES approach and the ES indicators, building commitment among actors, and choosing the ES indicators and the scales of application. The role and objective of the knowledge broker was to provide the civil servants with relevant and clear ES knowledge and to ensure that all relevant actors from different municipal departments were included in the process. In the beginning, a brief background document on topical ES research was produced and a kick-off workshop for a group representing a variety of municipal departments was organised (see Table 4 for boundary work during different phases). Next, a meeting between key civil servants from Tampere and the team of researchers was organised in order to select the indicators. The objectives of the *instrumental phase* (the next eight months) were to carry out the GIS analysis for the ES indicators; prepare their preliminary interpretations by the researchers; present, discuss and interpret the preliminary results with the civil servants in three meetings; and to communicate the ongoing project to a wider audience. The role of the knowledge broker was to facilitate and participate in the discussions in three meetings and to reconcile the needs of the civil servants and the feasibility of the GIS analysis. The views, comments and insights raised by the civil were taken into account while completing the GIS analyses, interpreting the results, and finalising the graphical indicator illustrations. In addition to discussions on the substance, it was important to ensure that technical requirements, such as data quality and the quality of the data transfer interfaces, were fulfilled for the GIS analysis. This demanded several exchanges between the GIS expert and the civil servants. During the *reflection phase* (last six months), indicator results were co-operatively discussed and interpreted, the ES approach and the method were reflected, and consideration was given to the use of the results. The researchers compiled results, preliminary interpretations of indicators, and the feedback from work meetings before sending them to the key civil servants for discussion and reflection. Following that, the indicator results were presented and discussed in a workshop, in which participants were divided into mixed groups with civil servants from different municipality departments. Each indicator (see two indicator examples in the Appendix) was discussed in the workshop from three perspectives: local interpretation of the ES indicator results, assessment of the state of the ES in Tampere and the use of the ES indicator results. Local interpretation focused both on the overall picture of the ES and green infrastructure in the area and on detailed consideration of certain areas. A knowledge broker facilitated the dialogues to ensure that everyone's views were considered in the group discussions and took notes on flip charts. The phase concluded with the production of the final report.

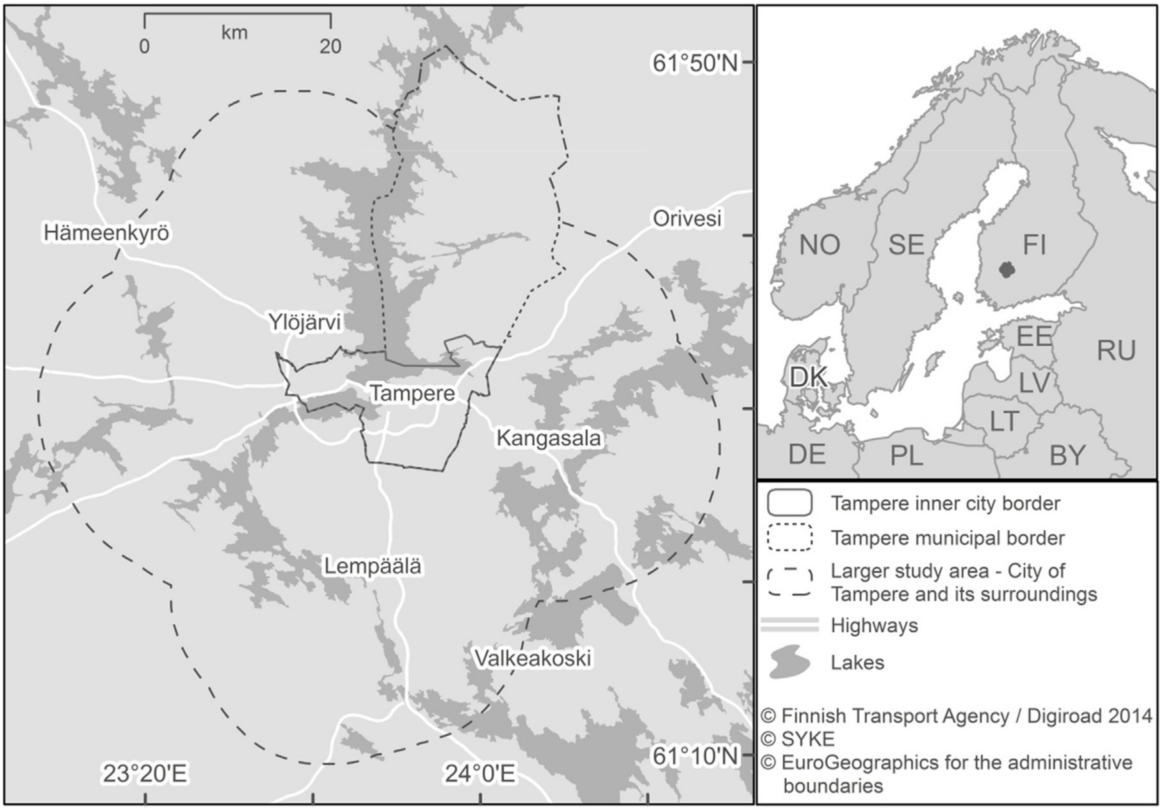

Fig. 1. Location of Tampere in Northern Europe and the three scales at which the ES indicators were applied in the project.

Table 2
Applied ES indicators (Söderman et al., 2012) and the geographical scale of application.

Indicator	Inner city	The municipality of Tampere	Tampere city region
The proportions of large uniform forest areas (over 10,000 ha)		×	×
The proportion of forest areas with a core area of over 200 ha		×	×
Of all core nature areas, the proportion with several ecological connections		×	×
Of the forest area, the proportion of border zones of forest areas		×	×
The proportion of forest areas larger than five hectares to all green and forested areas inside the densely populated area	×	×	
The proportion of land areas suitable for recreation (a) inside the densely built area and (b) outside densely built areas, of the whole land area of the urban region	×	×	
The proportion of inhabitants living no more than 300 m from an area suitable for recreation inside the densely built area	×	×	
The ratio of inhabitants to the total area of areas suitable for recreation	×	×	
The proportion of paved land (non-permeable surfaces) of the total land area	×	×	
The proportion of groundwater areas classified as risky	×	×	×
The proportion of paved land (non-permeable surfaces) of the total area of groundwater areas	×	×	×

3.3. Material and analysis

Two types of outputs were produced in the EVITA project. First, the ES indicators provided a large quantity of detailed instrumental knowledge on the green infrastructure and ecosystem services in the municipality of Tampere. The results (including GIS data, data sheets, maps, and the interpretations of the results in the final report) were delivered to civil servants. Second, the collaborative events and interviews produced qualitative material that gave insights into how the ES approach and indicators were taken up and understood by the civil servants and what ideas they had about the joint knowledge-production process. This article focuses on presenting the latter type of results, and the empirical material consists of documentation of the collaborative events during the EVITA project, the interviews conducted with civil servants for the purpose of this article (Table 3 and Fig. 2) and civil servants' written comments on the draft final report.

Seven semi-structured interviews (Table 3) were conducted with altogether eleven civil servants representing different departments of the municipality. This method was chosen in order allow expression of different perceptions freely and in-depth as the interviewees had different background and worked in different sectors of green infrastructure governance in the city. At the same time it was necessary to enable comparability and detailed qualitative analysis (Thalhammer, 2013). There were potential limitations with the interviews, such as civil servants possibly being biased in assessing the success of the process or interviewees influencing each other's opinions during group interviews. These risks were

Table 3
Departments participating in green infrastructure governance in the municipality of Tampere, their role, the number of interviewed civil servants and the dates of the interviews.

Department	Role in green infrastructure governance and management	No. of interviewees	Date of the interview
Infrastructure unit	Building and maintenance of green areas	2	5 Nov 2013
Sustainable Community unit (part of municipality's central administration)	Preparation and start-up of projects and initiatives related to municipality's environmental policy or sustainable development. Monitoring the environmental impact of environment-related decisions and projects. Collaboration with municipality's other units.	2	5 Nov 2013, 18 Dec 2013
Land use planning: local master plans	General planning of green areas: objectives, land allocation, connectivity of the green infrastructure	2	22 Nov 2013
Land use planning: GIS data and analysis	Maintenance and development of municipality's GIS data, carrying out GIS analyses for planning purposes	1	7 Nov 2013
Land use planning: detailed plans	Detailed planning of green areas as part of detailed plans: volume, purpose of use, significant nature sites	2	5 Nov 2013
Environmental Protection Department	Overall responsibility for environmental protection and nature conservation. Double role: participates in some planning processes and makes statements	2	7 Nov 2013

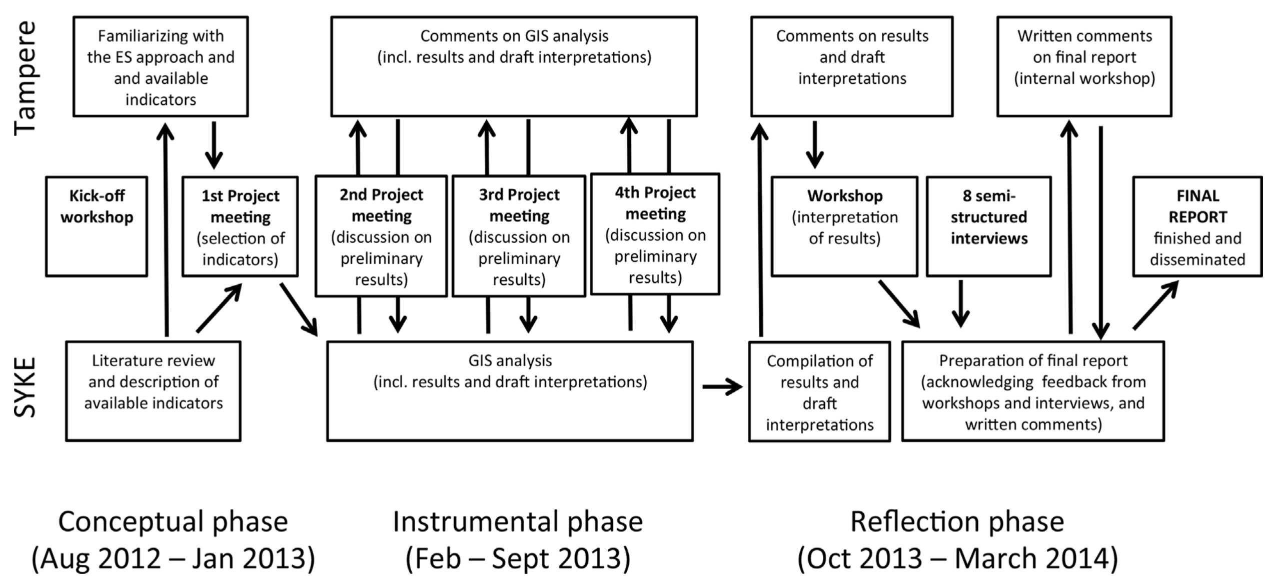

Fig. 2. The milestones of the ES indicator application. The boxes on the top row describe the tasks and responsibilities of Tampere, and the bottom row those of SYKE. The middle boxes are given to collaborative events. The arrows pointing up represent the flow of information and material from researchers to civil servants. The arrows pointing down describe feedback from civil servants to the researchers.

recognised and their potential influence on results was acknowledged in the analysis. The duration of the interviews ranged from 1 to 2 h. The interviews included four thematic sections dealing with:

(i) knowledge of green infrastructure and its relation to governance,
(ii) the ES and ES indicator approach,
(iii) the process and results of the indicator application, and
(iv) mutual understanding of urban green infrastructure.

The interviews were recorded and transcribed for detailed qualitative analysis. The responses were coded and grouped according to the interview themes and later according to the phases of the project and knowledge brokering repertoires.

4. Results

4.1. Civil servants' reflections on the knowledge production process

In the first *conceptual phase* boundary work included production of boundary objects (the background document and illustrative examples on the ES indicators), organising a kick-off workshop and a meeting with the key civil servants and facilitation of the indicator selection. The selection of indicators was facilitated by the knowledge broker and the GIS expert who produced illustrative examples and provided detailed information about the basic assumptions of the indicators and the technical feasibility of different application options. The researchers tailored the GIS analysis to meet the needs of Tampere and to take into account the data availability. The civil servants discussed both the ES approach in general and the available ES indicators and their geographical scales thoroughly first in the joint meeting and later in an internal meeting, where they selected the indicators that best fitted the ongoing planning processes. The civil servants perceived the selection of the indicators as a key phase in retrospect, as it had far-reaching consequences for the whole process and the usability of the results. Some interviewees stated that more effort should have been put into the indicator selection. They thought the selection as a difficult task, even though extensive material about the available indicators had been provided in advance and the issue had been jointly discussed. The interviewed civil servants stated also that knowledge gaps on green infrastructure had complicated co-operation between municipal departments in the past. For example, a lack of information about the overall coverage and state of green infrastructure was seen to hinder the collaboration. The impacts on green areas had previously been assessed as part of individual planning processes, but at the scale of the whole municipality, the state or coverage of the green

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infrastructure, and its recent development, were not the responsibility of any single department. The interviewees emphasised that open discussion and reflection was necessary in the early stage of the indicator application. They felt that it was crucial to have mutual understanding of the conceptual basis of the ES indicators and to share initial thoughts on what the ES approach could mean, since the ES approach was fairly new to most of the civil servants. They also commented that during the first phase, an atmosphere of trust and commitment between the researchers and civil servants as well as between different departments was created.

In the next *instrumental phase* boundary work included mainly communication between researchers and the civil servants: preparation of meeting documents for the project meetings, facilitating discussions in the meetings and communicating the ongoing project for wider audience. A particular emphasis during this phase was given to the discussions of the preliminary results. Interestingly, the civil servants wanted the GIS analyses and the associated results to focus on issues on which there was mutual, policy-level understanding and agreement and leave out politically sensitive issues that generated a lot of controversy. For instance, they regretted that demonstrating ES on areas with agreed, though not yet materialised land use changes would complicate future processes significantly, and did not want to include that in the final results.

In the final *reflection phase*, an effort was put particularly on joint interpretation and reflection of the indicator results. These took place in meetings and in the workshop, but also individually between joint events. Both the civil servants and researchers felt that it was necessary to combine researchers' interpretations with local knowledge and apprehension of the civil servants, acquired during their long work experience in Tampere. The interviewees perceived co-interpretation of the indicator results as a crucial factor for the production of usable place-based ES knowledge. Perhaps more importantly, it supported the use and influence of the ES indicators in the green infrastructure governance in Tampere. Due to the in-depth interpretations, the civil servants linked the indicator information to topical planning and management challenges. Tampere organised internal meetings during the process and one additional internal workshop at the end of the conceptual phase in order to gather the views of their departments on the draft final report. Judging from the interviews, the main motivation for the additional effort was to make the indicator results as useful as possible for concrete use. The participants found it generally positive that many ES indicators illustrated the state of green infrastructure in a large area, but on the other hand, they hoped that some analyses would have been carried out on a more detailed scale as well (which was not possible due to data and methodology restrictions). The participants also identified several errors in the maps (e.g. in relation to the connectivity of green areas and (mis)location of recreation areas) and proposed improvements for the indicator maps (such as clear visualisation of the main results, colours and legends). In assessing the current situation in Tampere as a whole, the participants were surprised by the number of spots, especially in the urban infill areas, where the sufficiency of green infrastructure is under pressure due to planned and potential land use. They proposed solutions to the problems, for example through compensating for the losses of green areas elsewhere.

The workshop participants identified several opportunities for the use of indicator results in the governance of urban green infrastructure, as well as for other purposes. These included preparation of a strategic and master plan and detailed land use plans, planning of infill development, carrying out impact assessment, planning of storm water control and the compensation, allocation, planning and management of recreation areas, and the preparation of collaborative plans and strategies with neighbour municipalities. The participants stated that the ES indicators enabled rather comprehensive consideration of the green infrastructure, which has a clear added value compared to traditional species-focused nature assessments. But at the same time they highlighted that because these ES indicators do not directly illustrate the quality or functionality of green areas, the results need to be utilised along with other data (such as results from citizen enquiries) or as a first step before more detailed quantitative studies of the ES.

4.2. *Critical factors influencing knowledge brokering*

The interviews and workshops revealed a number of critical factors that affected the knowledge brokering (Table 4). The nature of the *underlying ES concept* had significant influence on how the indicator application was planned and carried out and how the application of ES indicators facilitated cross-sector discussion. The emergence of the ES approach in policy documents had made it necessary for the civil servants to be aware of its content and relevance to urban green infrastructure governance, which potentially made the process attractive. Generally the ES approach was accepted and welcomed by most of the civil servants, but enough time in the beginning was needed to gain general-level understanding of the conceptual basis of the ES indicators. It was widely appreciated that the ES approach highlights the benefits to humans and is not limited, for instance, to conventional conservation issues that focus solely on species with legally protected status. The holistic nature of the ES approach supported the boundary work as well, by allowing for the inclusion of different views in the discussions. This was particularly important in the conceptual phase. On the other hand, the novelty and flexibility of the ES approach were also seen as weaknesses. The ES concept was strange and confusing to some civil servants, and they did not know what issues the ES indicators cover and what is their relation to conventional conservation approaches or to knowledge they already had acquired. Some interviewees suggested that they did not see the added value of the new approach and doubted whether the indicators could really be useful in land use planning or used as an argument in municipal decision-making. They were, for instance, concerned that the ES approach would be 'mis-used' in pushing certain interests and in neglecting biodiversity.

The results of the applied ES indicators provided part of the necessary background information for the revision of the local master plan of the city of Tampere as well as for other forthcoming processes. A *direct link to an ongoing planning process* was seen as a significant reason for the successful application of the ES indicators, both in terms of knowledge production and the potential dialogue between different jurisdictions. The interviewees stated that without a concrete link to practice, new approaches like ES might remain too abstract for meaningful discussions. But more importantly, it was seen as an advantage that the process was scheduled before the actual planning had started. One of the interviewees lamented that too often different departments meet at rather late stages of the planning processes, or in conflictual situations, which might hamper open dialogue and the establishment of personal contacts within the city administration. The civil servants were generally motivated by and interested in being involved in the process, and many interviewees pointed out that the involvement of different municipal departments in this case was broader and more active compared with other similar kinds of projects. At the end of the process, they explained that the application of the ES indicators had helped them to see both the unity of green infrastructure in the municipality and the places where more detailed ES studies are needed.

Frequent *iteration* was considered as a critical factor in the instrumental and conceptual phases of the process. The interviewees mentioned that mutual understanding both on the ES approach and the indicator results increased as the results were *interpreted*

Table 4
Chronology of main boundary work, key outputs and critical factors during the different phases of the ES indicator application.

Phase/time period	Boundary work	Outputs	Critical factors
Conceptual phase August 2012–January 2013	Initial contact between civil servants and researchers Production of two boundary objects: 1: A comprehensible state-of-the-art review of ES research in layman language 2: Illustrative examples of the ES indicators Organising of a workshop and a meeting Tailoring the process and indicators and facilitating the selection of the indicators by showing illustrative examples, facilitating discussions and asking detailed questions (in meetings and by email)	Project proposal and approved project plan Background document Pilot GIS analysis of some indicators Workshop presentations and memo Agreement on the indicators to be applied and the scales of the indicators.	Enough time reserved for discussing the key concepts and the selecting the indicators and scales
Instrumental phase February–September 2013	Communication related to the data availability by email Communication of intermediate results by email and in the meetings Facilitating the discussions in the meetings Co-authoring a short article for a local newspaper about the project	Preliminary and final GIS analysis of the ES indicators A newspaper article	Several iterations in commenting and interpreting the results Availability of data and functioning data interfaces
Reflection phase October 2013–March 2014	Organising a meeting and a wider workshop to discuss, interpret and reflect on the instrumental results and the usefulness of the ES indicators Co-production for the final report Production of the dissemination slides	Jointly discussed interpretations of the ES indicator results. Final report	Collaborative interpretation of the results between researchers and civil servants Joint reflection of the ES approach and the usability of the indicator results
All phases			Direct link to an ongoing planning process External and neutral leader and facilitator of the process The ES approach worked as boundary concept Institutional constraints and limited resources

in cooperation between different departments and the researchers. They felt that as all participating departments were involved from the beginning, all had been in an equal position and had an equal right to express their views throughout the process. The active role of the '*external*' *knowledge broker* in facilitating the process and the longer duration distinguished the process from the usual consultant assignments that dominate urban planning in Finland. This provided better opportunities for discussion and reflection. Having an external facilitator in the process was thought to prevent an over-emphasis on the views of individual departments and, instead, it enhanced equal dialogue on the indicators between departments.

A number of barriers for this kind of cooperation were also discussed in the interviews. It was recognised that administrative departments view and manage ES and green infrastructure from *different perspectives*, for example as conservation areas, recreational areas, or as agricultural and forestry areas. The views and aims differ and do not always appear relevant, comprehensible, or even justified to other departments and there is no commonly agreed framework or language for green infrastructure. Other identified barriers were thinning *resources* and the heavy workload of the administration. The interviewees stated that although a dialogue is seen as beneficial and necessary in green infrastructure governance, various other responsibilities are easily prioritised over 'voluntary' co-operation. One interviewee emphasised that it is challenging to introduce new approaches and practices, in particular when they require the adoption of new information, an allocation of additional resources and/or representation from a large number of departments. A concern that the information produced with the ES indicators may not be utilised to their full potential due to a lack of resources or policy-level understanding and commitment was expressed.

It was also highlighted that the *established land-use planning practices* and *decision-making culture* may restrict utilisation of the ES indicator results in real-world processes. Some departments may be excluded from the process or are only allowed to enter it when the most important issues have already been decided. The institutional realities may largely condition co-operation and discussion in the administration. No matter how (well) the boundary work is conducted in an individual process, more fundamental issues may prevent crossing over departmental boundaries. Many interviewees for example referred to the purchaser–provider split (referring to the principles of organising service provision in the city), adopted in Tampere in 2007. It was seen that this structure prevents spontaneous cross-sector interaction and collaboration and complicates the involvement of civil servants in projects that cross jurisdictional boundaries. Furthermore, although the civil servants perceived the space-explicit knowledge on the green infrastructure as useful, they were uncertain how, when and by whom the ES indicator results could be fed into the decision-making processes or how they would affect the decisions.

5. Discussion

The role of the knowledge broker in the different phases of indicator application proved to be versatile and dynamic, including realising different knowledge brokering objectives and associated boundary work. A boundary work continuum evolved and developed during the process according to the needs for knowledge production and use. Boundary work during the first conceptual phase can best be described as 'bridging' and 'supplying' knowledge brokering repertoires (Turnhout et al., 2013). It was important for the knowledge broker to interact and build a good relationship with the civil servants and to provide them with pre-digested and fit-for-purpose information about the ES indicators. The instrumental phase was characterised by the 'supplying' repertoire: the GIS expert carried out the indicator analyses in relative isolation and sent the results to the practitioners. The technical tasks were supported by meetings where the intermediate results were presented and discussed in order to tailor the analyses and to keep the civil servants interested in and committed to the process. In the final reflection phase civil servants and researchers collaborated in order to integrate the indicator results, local interpretations, and the indicator use into topical planning and management processes. The knowledge brokering repertoire 'facilitating' thus best describes this phase: the knowledge broker facilitated an open dialogue by circulating drafts and organising collaboration events for the civil servants. The ES indicator application as a whole in this case was dominated by a 'facilitating' repertoire, including a joint process and research-question framing, co-production of knowledge, and creation of commitment and trust (Michaels, 2009).

Our study was based on the idea that the ES indicators and the ES approach in general can be considered as a boundary object that can support establishing shared understanding (Harvey and Chrisman, 1998; Carsjens and Ligtenberg, 2007; Turnhout et al., 2007; Smith et al., 2013) and thus break the silos that exist between municipal departments in the governance of urban green infrastructure. The case findings suggest that the ES indicators can – if applied collaboratively and in connection to an ongoing planning process – bring different municipal departments together. This kind of process can also contribute to more successful knowledge exchange between science and decision-making. The interview results highlighted that either the researchers or the civil servants could not have developed this kind of information in isolation, as it was necessary to combine the conceptual and methodological expertise on the ES approach with knowledge on local environment and relevant policy and planning issues.

Nevertheless, the ability of a single process to create long-lasting dialogue and mutual understanding among departments is limited or at least very hard to document. Same applies to the effectiveness of the use of GIS-based information on ES: it is problematic to detect a direct use of ES knowledge for a specific decision. However, it is possible that knowledge produced for different purposes may accumulate and gradually contribute to long-term learning (Owens, 2012; Turnpenny et al., 2014). According to Turnpenny et al. (2014: 249) knowledge use is 'heavily determined by the ability of 'generators' to find the right moment to 'deploy' their knowledge. That appeared to be one of the key questions to the civil servants is this case as well.

We also came across some potential drawbacks of the ES indicators as boundary objects. Our results resonate with previous studies that indicate that the indicators may not be as neutral boundary objects as one might first consider them to be (Turnhout et al., 2007; Turnhout, 2009). In this case the role of the ES indicators as boundary objects was strongly tied to how the civil servants personally viewed the ES approach; whether they perceived it positively as a promising overarching approach or more cautiously as a threat to the traditional conservation approaches. In addition, there appeared to be differences in institutional cultures and resources and even tensions between departments, which may have increased the dominance of certain views in reflecting and interpreting the indicator results.

It was acknowledged that the use of the ES indicators can be affected – either positively or negatively – by a number of factors related to the indicators, their users, or to the policy context (Sébastien et al., 2014). According to the views of interviewees, our process was influenced by factors that mainly related either to the *users* (civil servants' perceptions on and attitudes to the ES indicators) or the *policy context* (ongoing policy processes, institutional realities). *Indicator factors* were not discussed explicitly and in detail by the civil servants. Nevertheless, we assume that the factors related with the ES indicators influenced how they were received and perceived, as well as how they enhanced or hindered discussion on green infrastructure. For example, the indicators that demonstrated the amount of green areas that had already before been assigned for building development though not yet built induced a lot of discussion in the workshops.

Our study reveals that besides the factors mentioned above, factors related to the knowledge production process significantly conditions the uptake of ES indicators and the discussion they generate. These factors could be labelled as '*process factors*'. An example of a process factor in this case was the iterative reflection of the indicators throughout the application, whose significance was evident in our study and has been emphasised in other research as well (e.g. Roux et al., 2010; Hegger et al., 2014). Depending on the context, the reflection can take different forms and be supported by an external knowledge broker or managed internally. Other process factors that were identified as relevant by interviewees were the long duration of the process, the relation of the ES analysis to concrete planning and policy processes, and the role of an 'external' knowledge broker (Table 4).

Our study suggests that the ES indicators can provide new and relevant information to civil servants involved in the governance of green infrastructure and enhance discussion between municipal departments. However, it is necessary to acknowledge the weaknesses and risks associated with ES indicators. One must be cautious not to assume that ES indicators would provide standard solutions to the governance problems or that they would automatically enhance balanced discussion between the parties involved. Experience from our study suggests that frequent iteration and flexibility are crucial in producing relevant information for concrete planning and in generating discussion and mutual understanding on green infrastructure.

6. Conclusions

Interactive knowledge production has been the subject of earlier research. It has been proposed that indicators find their way better into use when they are produced in a collaborative process between knowledge producers and users that acknowledges the principles of interactive and multi-dimensional knowledge exchange. Our collaborative process on ES indicators was divided into three phases: the conceptual, instrumental, and reflection phases, with different knowledge brokering repertoires and associated boundary work following and complementing each other, and partly overlapping as well. This specific case shows that a multi-way interaction supports the production of salient knowledge for the governance of urban green infrastructure and meets the needs of municipal multi-jurisdictional governance.

In practical terms, no ideal knowledge brokering continuum for the application of the ES indicators can be designed. Neither can the policy uptake of indicators be engineered. Instead, constant negotiation among the researchers and the knowledge users is needed in the spirit of knowledge exchange. These indicate a need for new roles for researchers, but also for civil servants working as a partner in the application process. However, a certain distance between them is required in order to maintain scientific independence and the quality of the ES indicators, especially if the researchers have a dual role as knowledge broker and knowledge producer. A critical level of satisfaction, 'the extent to which all participants develop positive feelings about the KE [knowledge exchange] process and outcomes' (Fazey et al., 2013: 26), on both sides guarantees that they are willing to put effort into the successful implementation of the application process. At the same time it is crucial resource-wise to tailor the boundary work according to both the governance problem and the indicator methodology at hand. If the ES indicators are planned as a response to a well-defined and limited question and the practitioners are already familiar with the approach, then a 'supplying' repertoire and more linear knowledge transfer might be sufficient. On the other hand, utilisation of more resource-intensive

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and interactive knowledge-brokering repertoires is justified if the purpose of interaction is to increase the utilisation of the indicators and to engage practitioners in knowledge production.

Based on our results and earlier, we propose some critical characteristics for boundary work when applying the ES indicators in different real-world contexts. First, the application must be based on the available data and on up-to-date information. Second, the application must be tailored to the planning and policy context. Thirdly, the application must be rewarding both for the researchers and civil servants. Fourth, the application must include planned multi-way interaction throughout the process. Fifth, the application must include a mixture of instrumental and conceptual activities. Finally, it is necessary to acknowledge that ES indicators are not 'neutral' boundary objects, but instead the discussions they generate are tied to the values and perceptions of both producers and users of the ES indicators.

We conclude that collaborative application processes can enhance the development of mutual understanding and capacity building among different actors, can enhance the generation of salient, credible and legitimate information, and finally enhance the use of indicator results in deliberative governance of green infrastructure. The application of ES indicators in real-world cases

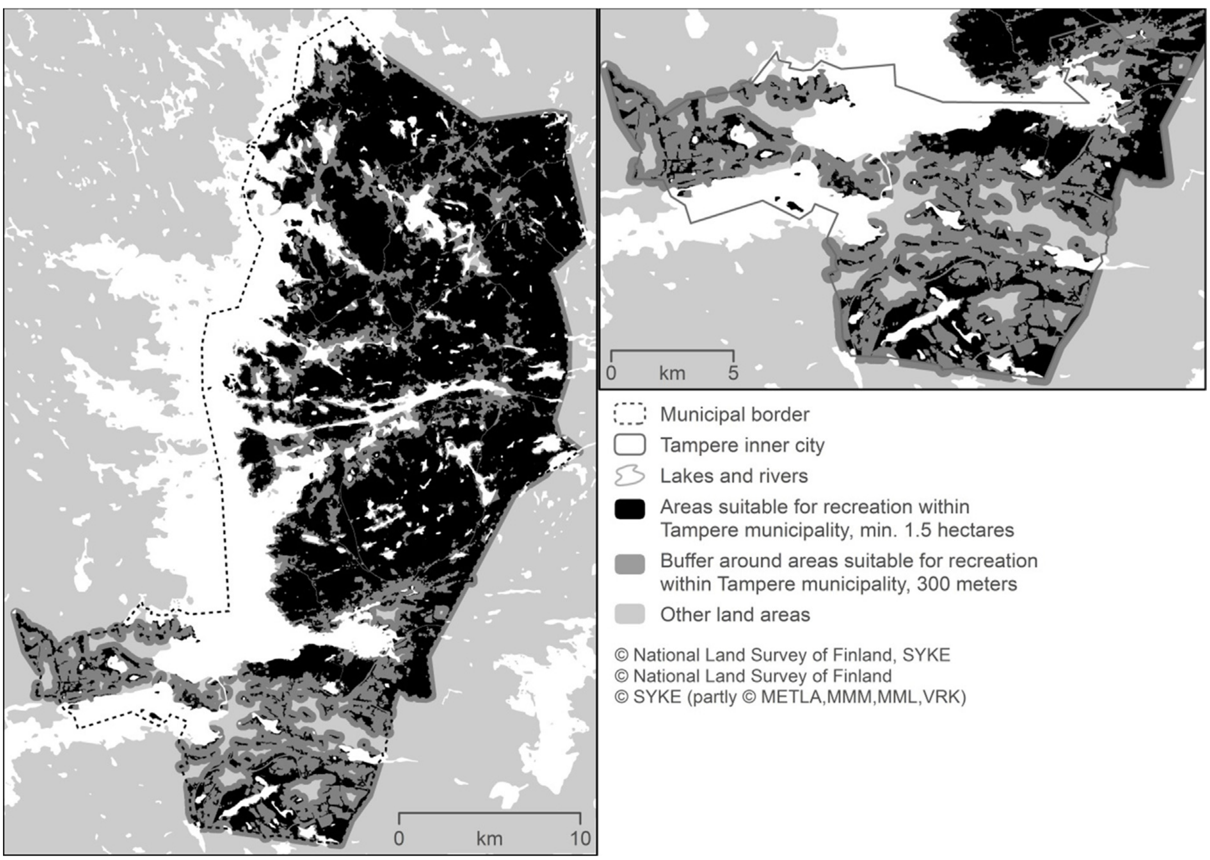

Fig. A1. Inhabitants living no more than 300 m from an area suitable for recreation inside the densely built area.

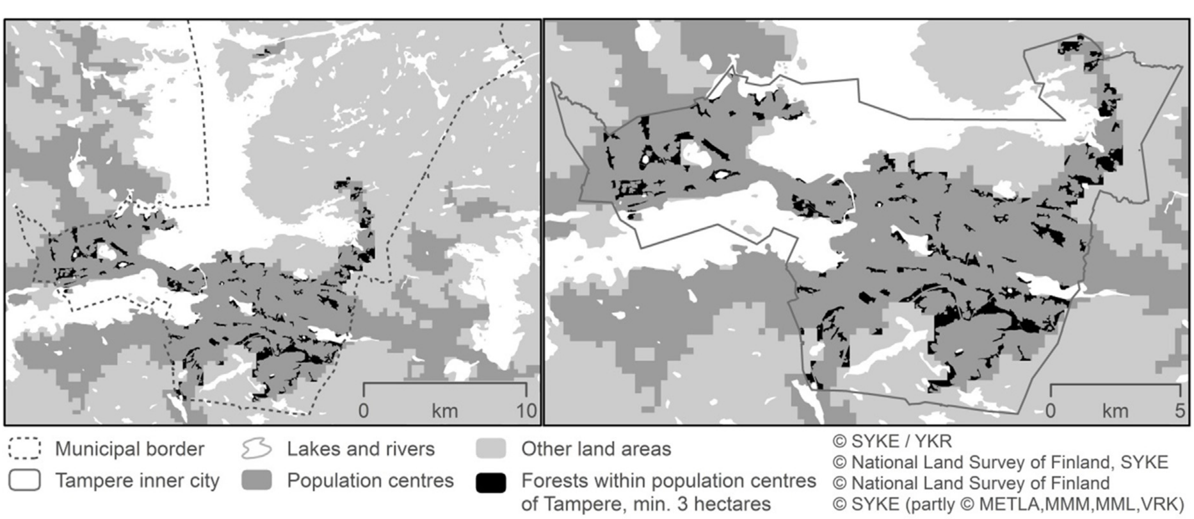

Fig. A2. The proportion of forest areas larger than five hectares to all green and forested areas inside the densely populated area.

Table A1
Indicators applied in the EVITA project and ecosystem services. The table presents a summary of the links between indicators (left column) and ecosystem services (other columns). The table is based on the detailed CICES v4.3 categorisation of ecosystem services (Haines-Young and Potschin, 2013). CICES is based on three sections: (i) provisioning, (ii) regulation and maintenance, and (iii) cultural ecosystem services. These are further divided into divisions, groups, and classes. In order to facilitate the discussion with the civil servants, the key content of these detailed sub-categories were summarised into informative ecosystem service categories (second highest row). The key connections between the indicators and ecosystem services are marked with "×", and secondary connections with "(×)". The heterogeneity of the connections cannot be presented in this general table. It demonstrates the various connections between different types of green areas and ecosystem services, and the various and complex interactions associated with the study.

	Provisioning						Regulation and maintenance				
	Agricultural and aqua-cultural products	Wild plants, animals and their outputs	Surface and ground water for drinking	Surface and ground water for non-drinking purposes	Materials from plants, algae and animals and genetic materials from all biota	Biomass-based energy sources (and animal-based mechanical energy)	Mediation of waste and toxics	Mediation of smell/noise/visual impacts	Mass stabilisation and control of erosion rates, buffering and attenuation of mass flows	Hydrological cycle and flood protection	Mediation of air flows
The proportion of large uniform forest areas (over 10,000 ha)		×	×	×	×	×	×	×	×	×	×
The proportion of those forest areas with core areas of over 200 ha		×	×	×	×	×	×	×	×	×	×
Of all core nature areas, the proportion with several ecological connections											
Of the forest area, the proportion of border zones of forest areas											
The proportion of forest areas larger than 5 ha to all green and forested areas inside the densely populated area		×		×			(×)	×	×	×	×
The proportion of land areas suitable for recreation (a) inside the densely built area and (b) outside densely built areas, of the whole land area of the urban region											
The proportion of inhabitants living no more than 300 m from an area suitable for recreation inside the densely built area											
The ratio of inhabitants to the total area of areas suitable for recreation											
The proportion of paved land (non-permeable surfaces) of the total land area			×	×					×	×	
The proportion of groundwater areas classified as risky			×	×							
The proportion of paved land (non-permeable surfaces) of the total area of groundwater areas			×	×					(×)	(×)	

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Table A1 (*continued*)

	Regulation and maintenance							Cultural				
	Pollination and seed dispersal	Maintenance of nursery populations and habitats, gene pool protection	Pest and disease control	Soil formation and composition	Maintenance of chemical condition of waters	Global climate regulation	Micro and regional climate regulation	Recreational use of nature	Nature as a site and subject matter for research and of education	Aesthetics and cultural heritage	Spiritual, sacred, symbolic or emblematic meanings of nature	Existence and bequest values of nature
The proportion of large uniform forest areas (over 10,000 ha)	×	×	×	×	×	×	×	×	×	×	×	×
The proportion of those forest areas with core areas of over 200 ha	×	×	×	×	×	×	×	×	×	×	×	×
Of all core nature areas, the proportion with several ecological connections		×						×		×		
Of the forest area, the proportion of border zones of forest areas		×						×				
The proportion of forest areas larger than 5 ha to all green and forested areas inside the densely populated area	(×)	×	(×)	(×)	×	(×)	×	×	×	×	×	×
The proportion of land areas suitable for recreation (a) inside the densely built area and (b) outside densely built areas, of the whole land area of the urban region								×	×	×	×	×
The proportion of inhabitants living no more than 300 m from an area suitable for recreation inside the densely built area								×	×	×	×	×
The ratio of inhabitants to the total area of areas suitable for recreation								×	×	×	×	×
The proportion of paved land (non-permeable surfaces) of the total land area					×			(×)				
The proportion of groundwater areas classified as risky												
The proportion of paved land (non-permeable surfaces) of the total area of groundwater areas					(×)			(×)				

gives the researchers valuable feedback for further improving the indicators. Iterations of conceptual considerations, technical development and applying indicators with practitioners are needed in order to fulfil the challenge of the ES indicators to inform policy, planning and management decisions.

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Appendix A.

See Figs. A1 and A2, and Table A1.

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