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Research paper

A methodology for evaluating transdisciplinary research on coupled socio-ecological systems

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ABSTRACT

Socio-ecological research, as conducted within the Long Term Ecological Research network in Europe (eLTER), is a relatively young field that studies coupled ecological and social systems to advance solutions for contemporary challenges in human-nature interactions. While many research and applied projects have been launched using a socio-ecological conceptual framework, there are few tested protocols to evaluate the effectiveness of such efforts at meeting their goals, e.g., goals relating to knowledge integration and influence on policy and practice, which distinguish this type of research. We suggest that such socio-ecological research may be conceptualized as an expression of the broader trend in science favoring transdisciplinarity, an approach that calls for research that fuses knowledge and methods from academia, practice, and broader society, with the goal of addressing shared public problems.

We conducted a literature review of definitions of transdisciplinarity, and used these definitions to distill the core characteristics of transdisciplinary research. From these characteristics, we developed a list of guiding questions for conducting a second literature review, this time to select evaluation frameworks deemed suitable for assessing transdisciplinary research whose content was socio-ecological in nature.

The resulting evaluative approaches were categorized into five groups: questionnaire models; mixed methods; staged environmental policymaking process review; the Research Embedment and Performance Profile approach; and case studies. Selected elements from these approaches were compiled and synthesized to create a six-stage framework for the assessment of interdisciplinary and transdisciplinary socio-ecological research projects and programs. The framework begins with qualitative analysis, followed by: quantitative analysis; data synthesis and visualization; the use of focus groups to reflect on interim conclusions, and, culmination with a final data synthesis and conclusions customized to the intended audience(s) of the evaluation. We provide an example of testing the first two stages of this framework using two Romanian Long-Term Socio-Ecological Research (LTSER) platforms.

1. Introduction

1.1. Ecology broadens its scope and mission

In response to growing regional and global ecological crises and the perceived inability of policy and management to adequately address them, an increasing number of ecologists and others have called for the integration of social sciences with ecological research (Singh et al., 2013; Balmford and Cowling 2006; Redman et al., 2004). These calls suggest that effective conservation policy and management require multiple and integrated forms of knowledge, including knowledge of ecosystems and their function, and the understanding of human societies, which interact with and depend on those systems (Vihervaara et al., 2010; Haberl et al., 2006; Hooper et al., 2005). In addition, effective communication and translation of knowledge across the science-policy interface (Perrings et al., 2011) and an understanding of how knowledge and policy play out to create social and ecological facts on the ground (*sensu* Grove et al., 2015) are needed.

Socio-ecological research, which encompasses the study of the human-environment system and society-nature interactions, is a multifaceted field. We use the term "socio-ecological research" to refer to research that studies aspects of coupled socio-ecological systems, integrated systems in which humans and nature interact (Liu et al., 2007). The term 'social ecology,' refers to several related – but distinct – lines of study. According to Fischer-Kowalski and Weisz (2016), social ecology draws from several disciplines, including political economics, geography, human ecology, and environmental history. They categorize the field into three core research areas: 1) society's biophysical

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structures, 2) biohistory and society-nature coevolution, and 3) regulation, governance, and sustainability transitions (Fischer-Kowalski and Weisz, 2016). Examples of distinct threads of socio-ecological research include the Vienna Social Ecology School, which was founded to study 'social causation of burdens on the environment,' the American tradition focusing on environmental ethics and eco-activism, and the International Long-Term Ecological Research (ILTER) network's adoption of long-term socio-ecological research (LTSER), which extended that network's traditional focus to encompass the study of social processes as well as ecological ones (Fischer-Kowalski and Weisz, 2016). The present study focuses specifically on socio-ecological research that originated among ecologists and other biological scientists who gradually sought to integrate social research, as is today practiced within the ILTER network.

While the distinct threads within social ecology have diverse origins and foci, they are all representative of Mode 2 science, which is characterized as socially distributed, transdisciplinary, cross-sector work that aims to address real-world problems and is accountable to multiple actors (Gibbons, 2000). Mode 2 science represents a shift from Mode 1 knowledge production, which is characterized by the dominance of conventional, experimental science, driven by scientists and academics (Nowotny, 2003). The newer paradigm – Mode 2–does not replace Mode 1; rather, it co-exists with it (Nowotny, 2003). A Mode 2 society means that context should be considered as an influence on all topics of scientific inquiry; for the field of ecology, this has meant acknowledging the fundamental interconnectedness of the ecological and social systems, and advancing frameworks for studying them.

1.2. Transdisciplinarity in socio-ecological research

While the term 'transdisciplinarity' can be traced to the early 1970s (Klein, 2004), it is a 1992 article by Patricia Rosenfield, writing about large-scale public health studies, that proposed a taxonomy of cross-disciplinary research that has been widely cited when scholars define transdisciplinarity (see, e.g., Stokols, 2010; Pohl and Hirsch Hadorn, 2008; Klein, 2006). In this taxonomy, *multidisciplinarity* refers to projects that involve several disciplines working in parallel to address a problem, defined by a coordinated or sequential work process. *Interdisciplinarity* is defined by a higher level of interaction and integration. *Transdisciplinarity* transcends disciplinary boundaries to create something new that becomes greater than the sum of its parts; it raises new questions and possibilities that could not have been raised by a single discipline, nor by a cross-disciplinary effort lacking coordination, integration, and close communication in a problem-solving context (Klein, 2010). Some scholars suggest that a transdisciplinary approach is necessary to carry out most complex, interdisciplinary team research projects, since, from their perspective, transdisciplinarity connotes a more inclusive team, higher standards for knowledge integration, and cooperation with non-academic stakeholders, thereby requiring sophisticated team communication and knowledge-sharing (Angelstam et al., 2013; Jahn et al., 2012; Klein, 2008; Pohl and Hirsch Hadorn, 2008).

Different scholars continue to debate the meaning of transdisciplinarity and to use the term in various ways (Zscheischler and Rogga, 2015). In this paper, we use the term to emphasize the core aspects of transdisciplinary research – an aim to address complex, real-world problems; meaningful collaborations, particularly between academic researchers and non-academics; and an openness to adapting methodologies as projects proceed (Zscheischler and Rogga, 2015; Roux et al., 2010; Polk and Knutsson, 2008). We conducted a literature review of definitions of transdisciplinarity, which is explained in more detail below, but since it is important to define transdisciplinarity for the purposes of this study, we present our own definition, which is particularly inspired by LTSER:

> A reflexive, collaborative approach to knowledge co-production, inclusive of academic and non-academic actors and stakeholders, to integrate diverse types of knowledge, consider risks and consequences, and generate practical solutions to societal problems.

Socio-ecological research, as conducted within European LTER – the regional European network within ILTER, (eLTER) – was conceived to incorporate different knowledge domains from diverse stakeholders to influence policy and ultimately to improve "ecological facts on the ground" (*sensu* Grove et al., 2015). These goals align with the goals of transdisciplinarity in a general sense. This is logical because the theoretical foundation of the socio-ecological research conducted within eLTER explicitly promotes transdisciplinary research across the sciences (Singh et al., 2013; Haberl et al., 2006). Since tools to evaluate transdisciplinary studies on nature-society interactions are so scarce, we deemed it appropriate to borrow approaches designed for the evaluation of interdisciplinary and transdisciplinary nature-society research and apply it to the type of socio-ecological research conducted within the LTSER network.

To this end, this article reviews approaches relevant for evaluating socio-ecological research, synthesizes these approaches into an original framework for the evaluation of socio-ecological research, and implements the first two stages of the approach, demonstrated through a case study of two Romanian LTSER platforms. While we focus our study on LTSER (described in detail below), we believe the evaluation framework we have developed can be applied to other socio-ecological programs and projects (such as those conducted through other projects and networks that have adopted the socio-ecological approach; for example, Future Earth,[1] The Stockholm Resilience Centre,[2] and the Institute for Social-Ecological Research).[3]

2. The emergence of long term socio-ecological research in eLTER

The Long Term Ecological Research (LTER) network was established in the United States by the National Science Foundation (NSF) in the early 1980s, followed in 2003 by the launch of the European LTER (eLTER) network. At its establishment, LTER program goals included the coordination of ecological research at the network level; improvement of comparability of data; delivery of high-quality data to scientists, policy makers, and the public to meet needs for decision-making; and education of the next generation of scientists (Knapp et al., 2012). A thirty-year review of the US LTER program conducted by an expert panel convened by the NSF commended the research network for establishing a functioning network of research sites that enabled research on a continental scale and collected long-term observational data that facilitated cross-site experimental studies (Michaels and Power, 2011). However, reviewers suggested changes for improving the program, particularly by addressing the tension between site-based and network-level research, challenges in data sharing, and for increasing research integrated with the social sciences to produce knowledge more useful for addressing complex environmental challenges such as climate change, sustainable development, biodiversity, ecosystem management, and environmental hazards (Michaels and Power, 2011). Due to these and similar recommendations (e.g. Redman et al., 2004; Singh et al., 2013; Sier and Monteith, 2016), European LTER network members proposed a new research framework – the LTSER platform – with a goal of integrating the social sciences into traditional ecological research. While the establishment of a formal network that put "socio-ecological research" explicitly in its name (Haberl et al., 2006) was specific to Europe, there was also evidence for this shift in the US LTER network (e.g. Phoenix and Baltimore Urban LTER). LTSER platforms have since proliferated across Europe and globally, forming an international network aimed at establishing cross-disciplinary, socio-

[1] See www.futureearth.org.
[2] See http://www.stockholmresilience.org.
[3] See http://www.isoe.de/en/home/.

ecological, place-based research venues.

Fischer-Kowalski and Weisz (2016) conceptualize social ecology as an archipelago situated between two "continents" – the Natural Sciences and Engineering on one side and the Social Sciences and Humanities on the other. Similarly, in their introduction to *Long-Term Socio-Ecological* Research (2013), Singh and colleagues show how past research strands originating from ecology, economics and engineering, land use studies, geography, anthropology, sociology, and history gave rise to four current-day research themes: environment and development, global environmental change, sustainability, and socio-ecological systems, all of which are studied today within the institutional framework of LTSER. Returning to the analogy of the archipelago, LTSER is not a single island; rather, it can be equated with the infrastructure – sailing vessels, communication networks, and meetings – used by the archipelago's inhabitants and visitors. Internal documents support this metaphor as a major strength of LTSER – the mobility of scientists within the network – but it should not obscure LTSER's central mission within eLTER: to advance place-based, long-term research related to nature-society interactions (Mirtl et al., 2013).

The added value of LTSER over traditional LTER research, according to its advocates, is the promotion of analysis, dialogue, and synthesis in an effort to understand how socio-economic and ecological components, processes, and dynamics interrelate (Collins et al., 2011; Haberl et al., 2006). As described above, a core aim of examining coupled socio-ecological systems is to produce societally-relevant knowledge that is applicable to policy making, planning, and management, or what has been termed transdisciplinary, or Mode 2 science (Nowotny et al., 2001). From the initial founding of the eLTER network, it was acknowledged that the high population density and longstanding human habitation of Europe made the concept of the "socio-ecological system" particularly relevant across the Continent (Mirtl et al., 2013). Accordingly, from the initiation of LTSER in Europe, leading scholars in the network have spoken about socio-ecological research within LTSER as inter-disciplinary and transdisciplinary since its research goals were to be directly related to addressing socio-ecological challenges (Maass and Equihua, 2015; Orenstein and Groner, 2015; Mauz et al., 2012; Haberl et al., 2006).

LTSER platforms are promoted as hubs for interdisciplinary and transdisciplinary research and data collection, characterized by a systems approach, a focus on ecological processes, and long-term, in-situ research at multiple spatial scales (Mirtl et al., 2013). Such research also aims to understand how human attitudes, beliefs, and behaviors contribute to socio-economic phenomena, and how these interact with the physical landscape and ecology (Collins et al., 2011; Haberl et al., 2006). The potential importance of LTSER platforms is not only in their ability to offer new research approaches and novel insights, but also to build potential for researchers to re-conceptualize their work practices, emphasizing the value of engaging with non-academic researchers and other stakeholders, with the shared purpose of making research more policy-relevant (Mauz et al., 2012). By conducting research at various spatial and temporal scales and encouraging learning in the context of an international network of researchers and policy makers such as LTSER, this shift aims to allow LTSER scientists and stakeholders to better understand and address socio-ecological challenges at local, regional, and global scales (LTER-Europe website, 2016).

2.1. Evaluating LTSER platforms

Since both the LTSER concept and the physical platforms are young (approximately ten years or less), little formal assessment has been conducted analyzing their aims, outputs, and consequences on the ground. For this reason, the eLTER network has initiated a comprehensive program to strengthen the research infrastructure of LTER in general, and LTSER in particular (LTER-Europe website, 2016). As part of this effort, there is also a current European Union-funded initiative to conduct evaluations at about 35 European LTSER platforms ("European Long-Term Ecosystem and Socio-Ecological Research Infrastructure (eLTER)" (H2020-INFRAIA-2014-2015)), as part of a larger effort to build capacity for this network (Haase et al., 2016). This project comes at an opportune moment, when a coordinated, formative evaluation of platforms may provide insights at an early stage when LTSER platforms may have more flexibility to make improvements based on the results. Early-stage evaluation may also present an opportunity to record baseline data at an early stage of platform development. However, at present, no comprehensive evaluation framework has been developed to assess trandisciplinary socio-ecological research at LTSER platforms. This paper seeks to address this lacuna and, in the process, suggest an evaluation framework that may in some cases be suitable for evaluating socio-ecological research in general, given the demands of conducting mode 2 science, which not only calls for a reflexive approach on the part of researchers but must also answer to other stakeholders across science and society.

2.2. Fundamentals of program evaluation

There are many reasons for evaluating research, including judging worthiness of activities, accountability, and as a learning tool that can be leveraged for improvement (Rossi et al., 2003). To begin, we distinguish between evaluation and assessment. Evaluation is usually summative, product-oriented, prescriptive, and judgmental (Straight, 2002). Assessment is often defined as formative, process-oriented, reflective, diagnostic, and flexible (Straight, 2002). It helps the individual or group conducting the assessment to understand how they are performing and progressing to enable improvement, whereas evaluation often results in a report card, usually for a client or decision maker, to enable reward or punishment. The evaluation framework ultimately developed in this paper is somewhat of a hybrid. It is both a report card-style evaluation that can provide a snapshot of accomplishments at a specific point in time, but since transdisciplinarity is a long-term and reflexive enterprise, the value of such an evaluation is to promote discussion and enable improvement. For this reason, we use both terms nearly interchangeably.

Evaluation design depends on timing. *Ex-ante evaluation*, which takes place before the start of a project, usually assesses alternative plans, as urban planners tend to do (Hill, 1968; Lichfield, 2005), or potential impacts, such as in an environmental impact assessment. This kind of evaluation is used to determine whether a project should launch, receive funding or a license, and/or to set a baseline so that an evaluation at project completion can better assess what was accomplished (Campbell and Rozsnyai, 2002). *Process evaluation* focuses more on how outcomes were produced than on the outcomes themselves, in order to improve the process (Blackstock et al., 2007). Within process evaluation, *formative evaluation* reflects on an ongoing project, providing feedback that may allow it to change direction or even to truncate or terminate the project (Taras, 2005). *Ex-post evaluation* assesses a project, policy, or program after its implementation, to measure outcomes and impacts as well as to take lessons that may improve its design for the future (Campbell and Rozsnyai, 2002; Rossi et al., 2003). Within ex-post evaluation, *summative evaluation* judges and reflects upon successful and less successful aspects of a project, with an emphasis on learning and knowledge accumulation (Blackstock et al., 2007).

A key factor in evaluation design depends on which actors initiate, fund, and conduct the evaluation, and for which audience(s) the evaluation results are intended. The term 'participatory evaluation' refers to a process whereby researchers, facilitators or professional evaluators collaborate with stakeholders to conduct an evaluation, often with the intent to expand decision-making and problem solving or to reallocate power in the process of knowledge production (Cousins and Whitmore, 1998). Cousins and Whitmore (1998) propose three key attributes of participatory evaluation: 1) control of the evaluation process, 2) stakeholder selection for participation, and 3) depth of participation.

Alternatively, if the primary goal of an evaluation is learning for the purposes of improving a project or process, a self-evaluation may be valuable (Späth, 2008). Some have noted that the centrality of the engagement of societal stakeholders in the research process has risen over the years, reflected in changes in terminology, from 'participation' to 'co-production of knowledge' and 'socially robust knowledge,' defined later in this paper (J.T Klein. 2017, August 30. Personal communication). Based on this background on transdisciplinary socio-ecological research and evaluation studies, we conducted two literature reviews in preparation for synthesizing our own evaluation framework.

3. Objectives and methods

Since we conceptualize socio-ecological research as conducted within LTSER as a manifestation of the broader trend toward transdisciplinary science, we began our study by conducting a literature review on the topic of transdisciplinarity vis-à-vis socio-ecological research. To do so, we reviewed definitions of the term 'transdisciplinary' by conducting keyword searches 'transdisciplinary and ecology' and "transdisciplinary and environmental and problem" in three major databases. Searches were conducted in the EBSCO; SCOPUS; and Web of Knowledge databases. We looked specifically for documents that defined transdisciplinarity in the context of environmental and ecological research; we excluded documents that didn't include clear definitions of transdisciplinarity. After eliminating duplicates; unpublished manuscripts; and papers deemed irrelevant to our research; we reviewed 112 documents; including 102 academic articles and book chapters; and 10 scientific reports. From these papers; we extracted and compared 15 definitions of the term "transdisciplinary" (see Appendix A in Supplementary file for a complete listing of definitions). Although we reviewed longer explanations as well; the 15 definitions listed in Appendix A in Supplementary file focus only on succinct definitions of up to about five sentences (shorter definitions were generally reflective of the content of the longer definitions). Using these definitions; we compared key characteristics of transdisciplinarity until we had distilled the concept into five defining attributes.

These characteristics were used as a reference to create a list of guiding questions for the second stage of the analysis, assessing evaluation frameworks (Table 1). Our guiding assumption was that, at least to some extent, in order to provide useful insights, evaluation methods should reflect or address the qualities of a transdisciplinary approach. Using these guiding questions (Table 1, right column), our next objective was to review literature particularly related to the *evaluation* of transdisciplinary socio-ecological research (i.e. evaluation frameworks that could provide answers to the types of questions compiled in Table 1). Since this literature was limited, we expanded our keyword search to include "transdisciplinary and evaluation" and "transdisciplinary and assessment," as well as using a snowball approach to include additional literature we deemed relevant. We chose not to include closely related search terms (e.g. participation) but to limit the search to evaluation approaches of *transdisciplinary* research. We considered literature relevant if – using the evaluation framework in a given publication – we could answer the questions in Table 1 in such a way that we were convinced we had a straightforward approach that could either a) address most of the aspects of transdisciplinarity listed above, or b) contribute a useful method for addressing at least one of the key elements listed in the table above, in a way befitting socio-ecological research. We sought methods to assess the quality of transdisciplinary research on human-environment interactions; we were not interested in methods for evaluating the socio-ecological system *per se*. After paring down our search results, we reviewed 40 relevant articles and reports. We then constructed a matrix comparing the various approaches vis-à-vis the elements listed Table 1.

An operating assumption for this review was that evaluations would be conducted by peer researchers also working on socio-ecological questions, particularly those affiliated with the LTSER network. It was further assumed that these researchers had limited expertise in evaluation studies, and if they did have experience conducting evaluations, it would likely be specific to their disciplinary training (this was mostly to assure that the evaluation methodology would be accessible to the broadest spectrum of researchers possible). For this reason, we favored evaluation methods that were straightforward to implement and did not require specific technical skills.

Our final objective was to select and synthesize elements from our findings to propose a project evaluation approach that could be used by LTSER platforms in particular and interdisciplinary and transdisciplinary socio-ecological research programs in general. The resulting evaluation approach has six stages (Table 4), the first and second of which were tested in a case study in Romania to envision how the approach can be applied (Box).

4. Results of literature review

Our comparison of 15 definitions of the term 'transdisciplinarity' yielded five core characteristics of transdisciplinary research. They include that the project or program: 1) transcends norms of a single field,

Table 1
Characteristics of transdisciplinary research and corresponding guiding questions for assessing evaluation.

Characteristics of transdisciplinary research	Guiding questions for assessing evaluation frameworks
Transcends norms of any single field. In addition to bringing together ideas from different fields and individuals with different backgrounds and training, there is a unifying theme, vision, or framework designed expressly for the endeavor (e.g. Klein 2010).	• Does the evaluation framework draw upon concepts or methods from different fields? • · Could the evaluation framework appropriately evaluate natural sciences research? • · Could the evaluation framework appropriately evaluate social sciences research?
Inclusive of multiple knowledges and often participatory. The approach values scientific knowledge across disciplines as well as valuing know-how and expertise from practitioners who may be neither scientists nor academics (e.g. Simon and Schiemer 2015; Lang et al., 2012).	• Are specialized skills required of an evaluator using this framework? • How easy/difficult does the framework seem to understand and carry out? • Does the framework include a possibility to assess the participation of diverse participants?
It aims to understand the real world in order to respond to pressing societal challenges (e.g. Polk 2014; Pohl and Hirsch Hadorn 2008; Max-Neef 2005).	• Does the method include indicators of impact in the social and biophysical world in addition to assessing scientific impact? (e.g. Wolf et al., 2013)
It is characterized by complexity. It addresses complex problems, usually in contexts of high uncertainty (e.g. Gibbons et al., 1994); the approach itself is complex, multi-dimensional, and diverse in perspectives, methods, communication, and context.	• Does the method capture the complexity of its object of evaluation by using multiple, diverse measures? • Does the method employ mixed methods?
It is "critical and self-reflexive" (Jahn and Keil 2015). Researchers are aware that they are working at the meeting point of science and society and that they are expected to balance the dual aims of contributing to scientific and societal progress Jahn et al. (2012)). "Self-awareness" is often intentionally developed as part of research through reflection about the process of doing research and how it may be improved.	• Does the framework investigate the research process, recording participant reflections about the project/program being evaluated?

Table 2
Objects of evaluation and their indicators.

What is being evaluated?	How is this term defined?	Indicators
Research process	Activities integral to the work of planning and executing data gathering and knowledge production, including networking, discussion, learning, creation of methodology, literature review, data collection, data analysis, synthesis, presentation	• Productive interactions (e.g. direct communications, boundary objects, and financial interactions Spaapen and van Drooge (2011) • Perceptions of involved parties (researchers, other stakeholders) about research process • Level of involvement • Degree of inter- or trans-disciplinarity of team
Outputs	Tangible products resulting from the research process such as "plans, projects, practices, and policies" Koontz and Thomas, 2006, pp.114)	• Publications, citations, or "reads" or "shares" on social media • Students/mentees graduated/advised • Representation on editorial boards, invited lectures, collaborations • Patents awarded • Membership in professional organizations • Public goods/products produced • Databases • Tools • Methods • Policies
Outcomes	Concrete changes in policy or facts on the ground	• Agreements reached • Restoration or habitat improvement projects initiated or completed • Changes to public policy • Changes to land management practices • Education and outreach programs conducted • Programs implemented • Land protected from development
Ecological impacts	Changes in the ecosystem that may be plausibly linked to the research process or resulting changes made in policy and practice i.e. "environmental outcomes" Koontz and Thomas (2006)	• Perceptions of changes in environmental quality • Changes in land cover, changes in biodiversity • Changes in environmental parameters (e.g. biological oxygen demand, contaminant discharge rates)
Social impacts	Changes in human attitudes, beliefs, knowledge, relationships, interactions, and culture i.e. "social outcomes" that may be plausibly linked to the research process or resulting changes in policy and practice Koontz and Thomas (2006)	• Changes in: levels of trust, conflict, legitimacy of an idea, policy, or practice • Size or strength of a social network • Distribution of ideas, etc. Walter et al. (2007)

2) is inclusive of multiple knowledges and often participatory, 3) aims to understand the real world, 4) is characterized by complexity, and 5) is critical and reflexive (Table 1, left column). From these attributes, we derived questions to guide our subsequent review of evaluation literature (Table 1, right column).

One challenge to evaluating the "degree of transdisciplinarity" in research is what we call the "transdisciplinarity spectrum;" where a given project, or project segment, falls on the spectrum of multidisciplinarity, interdisciplinarity, and transdisciplinary per Rosenfield's definitions (Rosenfield, 1992). These terms are often confused with one another, and a given project may be at different points on this spectrum at different points in time. Another possibility is that collaborators may have intended to execute a transdisciplinary project, but for whatever reason (e.g. lack of knowledge integration, lack of meaningful participation by certain participants), the project turned out to be an interdisciplinary project. These concepts are relatively fluid.

4.1. Review of evaluation approaches

Our survey of evaluation approaches aimed to review methods that could assess knowledge production processes toward decision-making, policy-making, and management at LTSER platforms. We were not seeking methods for evaluating socio-ecological systems; rather, we sought approaches that could evaluate whether the interdisciplinary and/or transdisciplinary knowledge production process was (or was perceived to be) achieving the goal of providing knowledge to empower more sustainable policy and management. It was thus useful to draw from a variety of fields of study and practice.

Using the guiding questions for assessing evaluation frameworks listed in Table 1, we selected a subset of approaches we deemed particularly relevant for evaluating inter- and transdisciplinary socio-ecological research projects. We paid particular attention to whether an approach a) accounted for participatory and reflexive aspects of transdisciplinary work; b) was flexible for different evaluation purposes and timing (i.e. ex-ante, formative, ex-post evaluation, self-evaluation); c) took into account a breadth of assessment criteria, and; d) whether it seemed reasonably straightforward to implement. Before reviewing existing relevant evaluation frameworks below, we first provide some general conceptual background on evaluation processes.

4.2. Focus of evaluation: process, outputs, outcomes, and impacts

The evaluation frameworks reviewed generally agreed that evaluation of transdisciplinary projects should consider both process and products (Carew and Wickson 2010). As with any evaluation, selecting the objects of evaluation is dependent on the evaluation's purpose. The frameworks reviewed emphasized the research process (e.g. communication, trust, knowledge transfer), outputs (e.g. publications, tools, etc.), outcomes (e.g. new agreements, policy changes, changes to management practices), and impacts (e.g. social consequences such as changes in social dynamics, environmental consequences such as changes in biodiversity). We draw upon diverse evaluation studies to define and give examples of objects of evaluation (Table 2).

Process evaluation often refers to examining the teamwork, including team composition, power dynamics, and effectiveness (Börner et al., 2010; Arnstein, 1969), which are often assessed with an interview or survey protocol. Questions may be asked in qualitative interviews to assess the quality of knowledge exchange (also called 'mutual learning'), information flow, management and leadership of the group, and institutional support for succeeding in these, such as professional development, communication tools, etc. A quantitative approach may also be taken. For example, Spaapen and van Drooge (2011) suggest quantifying three types of "productive interactions": *direct interactions* like phone, email, videoconference, and face-to-face conversations, *indirect interactions*, such as exhibits, models, or films, and *financial interactions*, in which an economic exchange takes place between

Table 3
Comparison of approaches for evaluating inter- and *trans*-disciplinary research.

Approach	Description	Key Features	Examples
Customized questionnaire	Mix and match from existing catalogs of questions to create a questionnaire or highly structured interview protocol for external or self-evaluation	Focus on scientific quality, integration, and project management	Defila and DeGiulio's Catalogue of Criteria (1999); Bergmann et al.'s Quality Criteria of Transdisciplinary Research (2005)
Integrative mixed methods (Haas et al. (2013)	Multi-disciplinary approach to assess broad-aim social programs	Integrates evaluation methods of, sociologists, psychologists economists and political scientists; identifies relevant stakeholders and their criteria for program success; includes cost-effectiveness analysis that is missing in most other methods	Alterman et al. (1984); Carmon and Hill (1988); Greene (1994)
Staged environmental program evaluation	Quantitative survey evaluation	Conducts surveys to collect detailed data about inputs, outputs and outcomes of an environmental research and management project	NAP (2008); Walter et al. (2007)
Research Embedment and Performance Profile	Mixed-methods evaluation, with focus on visualization of collected data and receiving feedback from evaluation subjects	Uses multiple criteria for five categories of evaluation −collaboration and visibility, science and certified knowledge, education and training, innovation and professional achievements, and public policy. Data are represented visually and shown to stakeholders for feedback toward adapting the research process	Spaapen et al. (2007)
Case study	Observations and in-depth interviews elicit reflections from stakeholders that can be analyzed in their respective social contexts	Creates a detailed, multi-perspective narrative of the research process and its impacts	Mauz et al. (2012); Maass et al. (2016)

researchers, such as a contract, financial contribution, or in-kind donation to a research program (Spaapen and van Drooge 2011, pp. 213).

Additionally, since one of the defining aspects of transdisciplinary research is that it engages non-academic stakeholders in the research process, it is important to account for the contributions and dynamics of these stakeholders, acknowledging that stakeholder engagement can range from being nominal to being characterized by highly asymmetric power dynamics to situations in which stakeholders do have influence and decision-making power (Arnstein, 1969). Stakeholders have been defined and typologized in various ways. A stakeholder may be any person or group directly affected by or having an interest in an issue (Reed, 2008; Elias et al., 2004). Blackstock and colleagues (2007) suggest that stakeholders are often involved in environmental research and policy initiatives to facilitate learning, understand multiple perspectives, and to increase buy-in and help resolve conflict. The salience of stakeholders has been shown to change when they acquire or lose power, legitimacy, and urgency (Mitchell et al., 1997). Mitchell also suggests that different or conflicting values or expectations are often involved in resource allocations and use decisions (cited in Elias et al., 2004). While formal stakeholder analysis is not within the scope of this study, an awareness of stakeholders' varied perspectives, interests, and positions are essential for conducting an evaluation that includes multiple perspectives.

The evaluation of research outputs (or products) usually refers only to publications and citations; here we include some additional measures such as: students graduated/advised, representation on editorial boards, invited lectures, interdisciplinary/inter-sectoral collaborations, etc. (Spaapen et al., 2007). Similar measures may be assessed in business and public policy arenas, such as reports authored, number of patents awarded, "reads" or "shares" on social media, membership in societal organizations, production of public goods, etc. (Spaapen et al., 2007). The field of evaluation research makes distinctions between *outputs*, *outcomes and impacts*. These terms should be clarified for a given evaluation depending on its purpose and audience of the evaluation.

4.3. Summary of approaches

Since there are very few evaluation approaches expressly designed to evaluate transdisciplinary socio-ecological projects and programs, it is timely to assemble best available methods. We have summarized five approaches from the broader assessment literature (Table 3) according to their potential for meeting the particular needs of interdisciplinary and transdisciplinary socio-ecological project evaluation. Each has specific strengths, which we draw upon for developing a new and comprehensive mixed-methods evaluation approach introduced below.

4.4. Questionnaire models

"Questionnaire models" draw from lists of sample questions which may be selected and ordered for written or interview-based surveys, by external evaluators or self-evaluation, based on the goals and limitations of the evaluation (Defila and DiGiulio, 1999; Klein, 2006; Jahn and Keil, 2015). In this method, evaluators distribute written questionnaires or conduct highly structured interviews with those whose work is being evaluated. The technique uses a high level of transparency, i.e. evaluators clearly explain the evaluation goals and procedure and how results will be presented and used. Evaluation questions aim to ascertain information about the project from the respondent's perspective; the target respondent pool depends on the goal(s) of the evaluation. Questions focus on research objectives and questions, how actors are involved, project organization and management, how well knowledge is integrated, the quality of scientific research outputs, the quality of knowledge and technology transfer, and competence of project management (Pohl et al., 2001). The number of participants surveyed and the mode of survey (e.g. questionnaire, interview, site visit, utilization of existing reports) are determined by the evaluators.

This approach uses a form familiar to most − the written or oral survey − and is easily customized to the purposes of a given evaluation. The approach is highly flexible and has the potential to be comprehensive or brief, depending on its purpose and available resources. Noteworthy is the fact that one version of this approach (Bergmann et al., 2005) designates as its first step an evaluation of whether the project was indeed transdisciplinary, a key step missing from most other evaluation methods. A questionnaire may also be used by a research group to conduct self-evaluations, which, given the focus in transdisciplinary research on reflexivity, integration, and learning, may be highly valuable (Späth, 2008).

4.5. Mixed-methods integrative approaches

Integrated assessment (also called integrative evaluation), was

Table 4
A framework for evaluating outputs, outcomes and impacts of socio-ecological research.

Activity	Purposes	Deliverables
1) In-depth interviews	Define the evaluation context; understand research goals and priorities; understand the "degree of transdisciplinarity" of research; assess perceived strengths, weaknesses, successes, areas for improvement, and failures (from diverse stakeholder perspectives); collect narrative examples. The focus is both on the process and impacts of research as well as the processes and impacts in the socio-ecological unit being researched. See, e.g. "social impacts" and "ecological impacts" in Table 2.	Audio recordings of interviews, notes, reflections
2) Qualitative Analysis	Distill key themes; determine gaps in the evaluation and prioritize questions to be addressed in subsequent stages	Transcribed and coded interviews, analysis of findings
3) Survey tool creation and distribution	Understand scientific productivity, including leadership positions, invited talks, number of students mentored, cross-sector collaborations, and/or other data, as well as perceived impacts of research, and consequences on social and environmental realities	Completed surveys
4) Quantitative Analysis	Analyze quantitative data collected from surveys and/or additional existing data sets; create graphical representations of data to use in focus groups	Analyses of quantitative survey and/or existing data sets; a report, including graphical representations
5) Focus group	Prompt researchers and stakeholders to reflect upon the preliminary results of the evaluation	Recordings and notes
6) Final synthesis and report	Synthesize qualitative and quantitative findings and feedback from focus groups; create a concise, useful product to communicate these results to the target audience	Final reports and presentations

developed for the evaluation of public programs with broad aims, such as social and physical neighborhood rehabilitation or major changes to a health system (Alterman et al., 1984). This approach combines methods from different fields (e.g. sociology, psychology, economics and policy analysis) to provide a comprehensive evaluation of a plan or project, with the aim of helping decision makers with both ongoing and long-term strategic decisions (Greene, 1994). This approach integrates different evaluation traditions with multiple objectives: 1) monitoring of outputs to track what has been accomplished by the program; 2) implementation analysis to provide insights about processes of decision-making and public participation; 3) economic evaluation for assessing cost-effectiveness and distributional effects; and, 4) goal achievement evaluation of program outcomes from a multi-group perspective (Carmon and Hill, 1988). The approach was developed to evaluate whether implemented programs resulted in intended (or unintended) consequences. The highlights of this approach include the fact that it takes a social perspective that is particularly interested in the equity effects of a program. It is adaptive, for example, in the way it encourages the use of existing datasets. Importantly, this approach includes economic analysis, which is essential, given the influence of funding on the existence of programs, but which goes unmentioned in virtually all the other approaches.

Another type of integrated approach, a sustainability assessment, was developed in the context of biosphere reserves, to monitor social activities that have a direct effect on the biophysical environment (i.e. Haas et al., 2013). This framework developed indicators in the social sphere (e.g. population dynamics, employment, income), the biophysical sphere (e.g. biodiversity/vegetation assessment, snow cover), and the "interaction sphere" between them (e.g. visitor frequency on hiking trails, skiing and related vegetation changes) (Haas et al., 2013). While this transdisciplinary approach was developed to monitor the socio-ecological system itself, the overarching conceptual model may be useful for integrating an assessment of a knowledge production process. First, the idea of this approach is to assess the social and biophysical spheres, as well as the interaction sphere between them. This model may serve as a useful example when trying to integrate understandings of the knowledge production process with the broader social sphere in which it is situated. Second, unique among integrated approaches, this assessment addresses society-nature interactions in the context of the biophysical sphere, as opposed to the other integrated approaches reviewed, which focused on urban environments. Lastly, this approach included a stakeholder analysis and review of potential scenarios. While we do not take up these elements per se in the assessment approach we introduce below, it is important to mention them, as they are widely used in transdisciplinary work.

4.6. Staged environmental research program evaluation

A multi-stage program evaluation tool was commissioned by the United States Environmental Protection Agency (EPA) in 2008 to "optimize efficiency and effectiveness, including the most effective mechanisms for allocating available resources and holding program managers accountable for results" (NAP, 2008, pp. 14). This model offers a staged approach, dividing a program into steps and reporting on achievements for each step. While terms may be defined differently depending on the agency using them and the type of research being evaluated, this methodology clearly defines and gives examples of program *inputs* (e.g. staff, training, facilities), *outputs* (e.g. articles, reports, management and policy guidelines etc.), and outcomes, specified by *intermediate outcomes*, like knowledge products, and *ultimate outcomes* like cleaner air and water (NAP,2008).

The unique contribution of this approach is that it breaks the process into highly detailed parts, recording examples of outputs from every stage of the process. This helps to keep a thorough, easily understood record of the program from "inputs" through "consequences". These stages are defined with greater specificity than in most other methodologies, including: inputs, activities, research outputs, intermediate outcomes from research, intermediate outcomes from users of research, intermediate outcomes from implementation, and ultimate outcomes.

4.7. Research embedment and performance profile

The Research Embedment and Performance Profile (Spaapen et al., 2007) aims to evaluate both the scientific and societal effects of a transdisciplinary research project, including the solicitation of feedback from the research group and other stakeholders, asking them to reflect upon the successes and shortcomings of their work and how this has been represented by the evaluation. The approach follows this process:

1) Understand the mission, self-image, contextual influences, and stakeholder make-up of the research group;
2) Construct a visual representation of the wider societal reference group for a scientific project ("embedment") and the degree to which a project serves the interests of this wider reference group ("performance");
3) Analyze and create a visual representation of the stakeholder environment;
4) Elicit feedback from the research group and stakeholders regarding the analysis conducted and potentially revise evaluation products based on it.

The visual representations constructed by evaluators are based on data profiles of the research group in five categories: science and certified knowledge, education and training, innovation and professional contributions, public policy, and collaboration and visibility. These data can be represented various forms, including spider graphs or table format. These graphical representations are then shown to the research team and other stakeholders to solicit their feedback, making the evaluation process participatory and reflective. This may be done in focus group discussions or in-depth interviews. The aim of this reflective part of the evaluation is to make the evaluation relevant and known to key stakeholders, increasingly the likelihood that it will be used to make immediate changes and/or improvements to the program.

While this method is time- and effort-consuming, requiring quantitative data collection as well as interviews, it produces data about the context of research, including research questions and goals, make-up of the research team, and a mapping of stakeholders. Reflecting good practice in transdisciplinary research, it includes a participatory, reflective element in which evaluators present their results and discuss them with the research team, providing an opportunity to integrate the results of the evaluation into research practices.

4.8. Case studies

The case study is a method used often in evaluation, in which a researcher develops an in-depth analysis of a case, which could be a program, event, activity, process, or group or individual (Creswell, 2014). Cross-site or comparative case studies can help identify similarities and contrasts across sites. For example, Maass and colleagues (2016) analyzed long-term ecological and social data at 15 long-term ecological research (LTER) sites, enabling them to examine and compare land-use and cover change between the cases, and to elucidate relationships between ecosystem dynamics and public policy. Another comparative study piloted a new methodology for rapidly assessing ecosystem services at 35 LTER sites across Europe (Dick et al., 2014). Case studies often gather data using interviews (Creswell et al., 2003). Interviews can be highly structured, semi-structured, or informal, the last of which may be especially appropriate for exploratory research at the start of an evaluation process (Creswell et al., 2003). A constructivist approach to interviewing values open-ended questioning and the flexibility to adapt as new information comes to light (e.g. altering methodology or revising questions). Such interviews may allow evaluators to understand the research objectives from multiple perspectives, the context in which research has been conducted, and the results, emphasizing close attention to detail in observing and interpreting social meaning (Helms Mills et al., 2010; Guba and Lincoln 2001). We suggest that because socio-ecological research within ILTER relatively new, case studies may contribute a helpful narrative aspect to evaluations of research activities.

5. A suggested framework for transdisciplinary socio-ecological project/program evaluation

Here we propose a framework for evaluating transdisciplinary socio-ecological research projects and programs by integrating the most suitable components from the methods reviewed above. The aim of this framework is to enable researchers to conduct an evaluation that will provide narrative, quantitative, and visualized data about problem context, research context, achievements, and shortcomings of the research, and related impacts on the socio-ecological system. We have designed this approach to be as accessible as possible so that individuals with backgrounds in academia, practice, and other stakeholders can carry out the evaluation process, either as external evaluators or as part of a self-evaluation. However, since this framework was created with LTSER in mind, we have assumed that it would most likely be used by ecologists and social scientists working to conduct evaluations of their colleagues' LTSER platforms within the network.

This is a staged, adaptive approach inspired by grounded theory (see, e.g., Charmaz, 2014). By 'staged', we mean that data and knowledge acquired at a particular time is built upon in subsequent stages. By 'adaptive', we mean that based on new information, a change in audience, or stakeholder or evaluator concerns that may arise, the methodology may be modified as it proceeds. To be 'inspired by grounded theory' means that the evaluator does not begin the process with a hypothesis or firm expectation of what they will find; rather, they use their expertise and common sense to proceed with the methodology but keep an open mind about what they will find and remain reasonably willing to adapt their understanding and protocol as more information is learned.

The first stage of our framework adopts a case study approach. The researcher selects a target project or program and conducts in-depth interviews with researchers and non-researcher stakeholders to understand research goals and priorities, perceived achievements and challenges, and, if possible, narrative examples of successes and failures. The evaluator should have in mind all the categories listed in Table 2, so they can guide interviews to provide information about research context and research process, as well as about successes, failures, progress, and obstacles to the social and ecological issues at the heart of their research. This is an opportunity to understand the context of research, the intended objectives of the research, and ultimately progress that has been made in knowledge production, as well as in policy and implementation. This stage also allows evaluators to assess "how transdisciplinary" the research actually is, according to the characteristics outlined in Table 1. The second stage constitutes the analysis of this qualitative data. Interviews are transcribed and coded according to accepted methods of qualitative research (Saldaña, 2015). This stage results in themes, insights, and intepretations that may be used to richly describe the context and status of a project or program, or as a starting point for further inquiry and/or reflection.

Based on the themes and interim conclusions drawn in the qualitative stage of the evaluation (stage 2), a survey tool is then designed to collect quantitative data from a much larger number of respondents than could be reached in the first stage (stage 3). This survey further investigates key issues driving the evaluation as well as insights and themes uncovered through the in-depth interviews. Data can be analyzed using statistical methods to find significant or intriguing trends and relationships (stage 4). Such analyses will help to draw out key indicators that can be used to create data visualizations and infographics.

After integrating an in-depth understanding of one or more cases with supporting quantitative data, the evaluators are equipped to draw preliminary conclusions. With care to how they would like to represent and communicate the preliminary conclusions, evaluators should create a presentation that includes visualizations of their findings that will be used to provoke questions and catalyze discussion within focus groups comprised of target stakeholders (stage 5). Comments arising from the focus group discussions are then incorporated into the final product of the evaluation. The framework for evaluation of socio-ecological research is outlined in Table 4. We provide a preliminary working examples of stages 1 and 2 of this framework in the accompanying Box.

The "who" and "how" of initiating, conducting, participating in, and funding the evaluation can contribute to the nature of the tone, power dynamics, and content of an evaluation. Our approach does not proscribe a particular configuration of these factors. Rather, we assume that these elements should fit the context of the evaluation and that the aim of the evaluation should be to produce 'socially robust knowledge' (Nowotny et al., 2001). Nowotny et al. (2001) have argued that Mode 2 science coincided with a shift from 'reliable' to 'socially robust' knowledge. While the standards of reliable knowledge continue to be upheld, socially robust knowledge requires three additional tests. First, it should be checked for validity in the real world, in addition to inside the "laboratory". Second, social robustness is usually attained by involving an extended, "socially distributed" group of experts that

incorporates diverse mixes of knowledge. Finally, since society is an active partner in the production of this type of knowledge, the knowledge must be repeatedly tested and adapted (Nowotny, 2003). Evaluators are meant to be cognizant of these ideas during the evaluation. For example, a side conversation about power dynamics in the research or policy making processes might occur during an in-depth interview, or a representative from a funding agency might ask to attend a focus group session, which might change the dynamics of a discussion. This level of attention to context is particularly suitable for transdisciplinary research, and perhaps, in the broader context of Mode 2 science, even predominates (Nowotny et al., 2001).

Box Application of proposed socio-ecological assessment framework (stages 1 and 2: in-depth interviews and qualitative analysis) in two Romanian LTSER platforms.

Stages 1 and 2 of the proposed evaluation framework have been conducted at two Romanian LTSER Platforms, the Danube Delta Biosphere Reserve[4] and the Small Island of Braila Natural Park.[5] Pioneers of socio-ecological research at the University of Bucharest Department of Systems Ecology, Angheluta Vădineanu and his team, initiated socio-ecological research platforms in Romania and helped them to gain official eLTER recognition soon after Romania joined the EU in 2007 (Adamescu, in preparation). These study regions were conceived to monitor and understand changes in both the ecological and social systems, as well as to foster and maintain relationships with key institutional and local stakeholders in these regions. Two evaluators (both social ecologists and authors of this paper) teamed up with the Romanian LTSER team leads (both systems ecologists), to conduct an assessment of the two platforms. In stage one, the joint team set up site visits and meetings with stakeholders at each site. Sites and stakeholders were chosen to provide exposure to the key issues and players, as well as the research, policymaking and management activities of the platforms. Stakeholders interviewed included research scientists, public land administrators, government officials and local residents (including farmers, fishermen and tourism operators). Seventeen interviews were conducted. An interview protocol was used as a guide (Appendix B in Supplementary file), although interviews were kept informal. During the tour of the platforms, the evaluators had ample opportunity to reflect with the platform managers after interviews and to get a better understanding of the context of local issues.

Stage 1: In-depth interviews

Interview data contained information and insights from a variety of stakeholder perspectives. We first used notes from on-site interviews to record insights vis-à-vis our framework's objectives (per Table 4), which allowed us to get an overview of the case. Then, we transcribed and coded the interviews according to accepted methods of qualitative research, which we describe below ("Qualitative analysis"). Finally, we used our listing of evaluation indicators (Table 2) to list a summary of our findings and items for follow-up.

The following insights were based on notes taken during interviews:

Defining the evaluation context

- While the platform visit was initiated by outside evaluators, Romanian systems ecologists welcomed the opportunity, with the hope of strengthening the performance of Romanian LTSER platforms.
- Prior to 1990, government-driven economic development projects drained parts of the Danube Delta marshes to make way for agriculture and fish farms. Since 1990, some of these projects have been "reversed" to prioritize conservation and a shift to eco-tourism.
- There is a strong and ongoing legacy of Communism's influence on environmental policy and management. This affects citizens' ability to trust one another, encourages skepticism about motives behind new laws, and provokes a desire to take immediate advantage of natural resources due to feelings of uncertainty about the future.

Understanding research goals and priorities

- There is a core focus on mapping ecosystem services, which is partly due to Europe-wide initiatives to that end.
- Ecological restoration projects are currently underway. These projects attempt to reconstruct an ecosystem to restore ecosystem functions as they were prior to development. These changes are being monitored closely by researchers.
- At the Small Island of Braila LTSER Platform, a participatory process assembled a Scientific Council and other stakeholders to create a local land management plan, which currently serves as the guidelines for land management on the island, although not without conflict.

Understanding the "degree of transdisciplinarity"

- Romanian LTSER scientists have advocated a transdisciplinary approach to research for decades, and their team has been a prominent driver in Romania for implementing this way of thinking and working.
- Systems ecologists initiate most research endeavors, but they recognize that good relations with other researchers, and with regional and local stakeholders, are necessary for a successful transdisciplinary research process.
- Systems ecologists have built relationships with economists, sociologists, foresters, and government scientists from academic and governmental institutions across Romania, and tap these individuals when they need additional expertise and/or need to meet EU requirements for transdisciplinary research.
- The European Union funding agenda, which has inserted new terminology and expectations into their funding mechanisms (e.g. ecosystem services, public participation), has catalyzed the process of including stakeholders in research. This has granted legitimacy and financial support to Romanian scientists' existing transdisciplinary efforts.

Perceived strengths, weaknesses, successes, and failures

- Tourism might be better supported if end-user stakeholders better understood interconnections between rules and regulations, ecological and cultural heritage protection, and public awareness and education, on the one hand, and a successful tourist industry on the other.
- Socio-ecological research demands ongoing communication between researchers and stakeholders. While researchers believe that broad, ongoing participation is required to maintain trust, reciprocity, and buy-in, other stakeholders often need to feel that, in order to participate, they will

[4] See more information about this platform at https://data.lter-europe.net/deims/site/lter_eu_ro_001.

[5] See more information about this platform at https://data.lter-europe.net/deims/site/lter_eu_ro_006.

gain concrete and immediate benefits from doing so.
- Researchers can play a key role in facilitating policy-making processes by serving as trusted intermediaries and knowledge brokers.
- Perceived inequalities (e.g. perceived differences in pay, status, or role) may create barriers to cooperative activities between university researchers and researchers from independent research institutions, such as setting an integrative agenda for research.

Narrative examples

A compelling set of stakeholder narratives about the Small Island of Braila Natural Park – also an LTSER platform – resulted from a meeting with the mayor of a village bordering the protected area, his municipal staff, and our researcher-hosts, all sitting around the same table.

Our researcher-hosts talked about their role in establishing the Small Island of Braila Natural Park and the Scientific Council that provides expertise for its management. They explained the historical context behind the local branch of the Forestry Administration taking over management of the park.

The mayor was concerned with economic growth opportunities in the area, and with securing access to the park's natural resources, such as grazing land, hunting and fishing rights and access for local residents.

A member of the government staff (also a local veterinary technician) talked about the fact that while many of his peers had gone abroad to better economic opportunities, he felt connected to the land where his grandparents had been shepherds, and he loved the peace of the local countryside, where he owned a property. He didn't want to leave. He wanted to be able to make ends meet in his family home.

The three municipal staff members, all local residents, described changes in access to natural resources that had occurred since the establishment of the protected area. Local lakes had been silted. The grazing of animals was prohibited in the park, but there had been reports of illegal grazing. Fishermen – even those with permits – were prohibited from fishing.

All parties agreed that they would like to develop nature tourism in the area, but all cited bureaucratic hurdles to doing so.

This is just one example of the kind of descriptive context that field interviews can provide. This particular narrative resulted from an impromptu group interview that arose after a scheduled meeting with the mayor.

Stage 2: Qualitative analysis

Our second data analysis exercise was to take the categories and indicators from Table 2 (above) and use data contained in interview transcripts to fill in this chart as fully as possible. This provided a snapshot of data collected on the research process, outputs, outcomes, ecological impacts, and social impacts, and made it easier to see gaps in data collection that may be filled in during later stages of the evaluation. This chart is shown in full as Appendix C in Supplementary file.

Finally, we used the qualitative data analysis and research software Atlas.ti to code interviews and grouped codes to derive themes. The process of coding is often done in two iterations (E. Eisenberg. 2017, June 15. Personal communication). First the interview transcript is read closely (a "technical read"), with an effort to "stay close to the text" and name the topics being discussed. The second reading often pays more attention to broad concepts (a "conceptual read") (E. Eisenberg, ibid.). This process generates a long list of "codes". These codes can then be grouped according to how closely they are associated with one another, and generally the distinct groups that result are called "themes". These themes can help to organize narratives for reporting results. The results of this coding analysis were outside the scope of this paper, but are planned for future publication.

Reflection on the case study

While transdisciplinary socio-ecological research can be evaluated according to clearly defined parameters, there is also an element of "I know it when I see it." We would argue that there is no substitute for a site visit, and, similarly, there is no substitute for the opportunity for long conversations with researchers, institutional stakeholders, and locals "in-situ." Interviews provided rich narratives in context, and along with supporting qualitative data, as well as the quantitative data that will supplement them later, we believe a multi-faceted, comprehensive picture will result, enabling evaluators to understand whether the research program is influencing its target objectives for actionable knowledge.

The approach resonated with us as evaluators since it demonstrated a unity of method and content, in the sense that the evaluation approach itself was transdiscplinary while investigating whether the object of evaluation – here the research programs of two Romanian LTSER platforms – was transdisciplinary.

There was an inherent bias in the fact that while we were external evaluators, we were also colleagues from within the LTSER network who could reasonably expect to collaborate with the researchers who hosted us in future projects after the evaluation. In addition, since the research team accompanied the evaluators and also provided translation services for us, it is likely that we as evaluators were exposed to a significantly greater extent to the views of this core research team. Finally, the grant that funded the site visits for the in-depth interviews –provided by a Horizon2020 grant from the EU – was disbursed to the Romanian research team and then the evaluators expenses were reimbursed from them.

Results from this qualitative investigation (see Box) (stage 2) will be used to create a questionnaire for distribution to systems ecologists, other natural scientists, social scientists, government researchers, land managers, and local government representatives (stage 3). The results of the questionnaire survey will be analyzed and results will be presented in report form and visually (stage 4). Results will then be discussed in focus groups with stakeholders (stage 5). This feedback will be integrated into a final evaluation (stage 6).

6. Conclusions

6.1. Implications of the proposed evaluation framework for socio-ecological research

The impetus for this work was the realization – following a review of the socio-ecological program literature – that there are virtually no comprehensive frameworks for assessing the efficacy of such work (Axelsson et al., 2013; Buizer et al., 2015). Considering that such projects have been proliferating within the ILTER network (Müller et al., 2010) as well as in other research networks (e.g. Future Earth initiative), this appears to indicate an important gap in what is otherwise assumed to be reflexive research. The assessment of social and environmental impacts is 'rather unexplored "terrain"' (European Commission 2005, pp. 9). Further, it has been explicitly noted that regarding the transformation in the production of research toward being more collaborative, more interdisciplinary, more transdisciplinary, and more oriented toward societal needs, assessment "does not happen without difficulties because there is no broad consensus about how to evaluate research in a more comprehensive way" (Spaapen 2015, pp. 36).

In the absence of such a framework, we have drawn from diverse sources to formulate our proposed methodology. This approach aims to: build "self-awareness" around key aspects of socio-ecological work; identify strengths and weak spots regarding program management, understand the interdisciplinary and transdisciplinary nature of collaborations, and which of these may constitute effective or ineffective work; align research priorities with the issues perceived as important to stakeholders besides the academic researchers; and − of course − emphasize problem-solving in the socio-ecological system. While the qualitative and quantitative stages of the evaluation primarily examine the status quo, these data are used to create prompts that can be used to solicit insightful comments from focus groups. The assumption is that suggestions for adapting the research process will be viewed more favorably and may be more likely to be adopted if they originate from the stakeholders themselves.

The proposed framework is flexible and can be implemented at the scale of a single project or program. There are clear caveats in trying to assess an endeavor in the short-term which is poised to effect societal change over the long term, and then trying to package discrete results about a complex, dynamic research network. However, we believe we have identified a gap in methods, and the result of our literature review has itself been a transdisciplinary endeavor in that it has applied a management mentality (i.e. "what gets measured gets done") to the research process. We hope this review and our suggested assessment framework serve to provide a clear path forward for determining whether socio-ecological research, at least as it is practiced within the ILTER network, represents the paradigm shift that ecologists and others have envisioned, and whether that in turn, is having desired impacts on society, policy, and the biophysical environment.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2017.10.074.

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