

## Intermediate ecosystem services: the origin and meanings behind an unsettled concept

Karl A. Lamothe & Ira J. Sutherland

**To cite this article:** Karl A. Lamothe & Ira J. Sutherland (2018) Intermediate ecosystem services: the origin and meanings behind an unsettled concept, International Journal of Biodiversity Science, Ecosystem Services & Management, 14:1, 179-187, DOI: [10.1080/21513732.2018.1524399](https://doi.org/10.1080/21513732.2018.1524399)

**To link to this article:** <https://doi.org/10.1080/21513732.2018.1524399>



© 2018 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.



[View supplementary material](#)



Published online: 28 Sep 2018.



[Submit your article to this journal](#)



Article views: 2337



[View related articles](#)



[View Crossmark data](#)



Citing articles: 11 [View citing articles](#)

## Intermediate ecosystem services: the origin and meanings behind an unsettled concept

Karl A. Lamothe <sup>a\*</sup> and Ira J. Sutherland<sup>b\*</sup>

<sup>a</sup>Department of Ecology and Evolutionary Biology, University of Toronto, Toronto, Canada; <sup>b</sup>Department of Natural Resource Sciences, McGill University, Ste. Anne de Bellevue, Canada

### ABSTRACT

Some ecosystem services (ES) bestow society with obvious tangible benefits such as nourishment from food and water (i.e. final ES), whereas other ES benefit society through complex pathways such as maintaining the resilience of ecosystems and the final ES they provide (i.e. intermediate ES). However, the term ‘intermediate ES’ has remained loosely defined and some authors are now questioning the term’s applicability. To uncover the meaning and origin of the intermediate ES term, we reviewed the literature from 2000 to 2016. We found that the term originated in economics (early 2000s), shifted into ecology in the late 2000s, and its use has grown since. Intermediate ES have been commonly defined as indirect benefits, less commonly as types of ecological components, and occasionally as supporting and regulating ES. We explore these analogies, provide a timeline of the term’s use, and discuss pros and cons of the terminology. We recommend that intermediate ES should be defined in specific (often local) contexts considering social factors such as demand for ES and if the service is a key step along an identifiable pathway toward final ES delivery – considerations we illustrate using coastal temperate forests as a case study.

### ARTICLE HISTORY

Received 26 February 2018  
Accepted 10 September 2018

### EDITED BY

Matthias Schröter

### KEYWORDS

Ecosystem services; final ecosystem services; intermediate ecosystem services; regulating services; supporting services; terminology

### Introduction


A challenge delaying implementation of the ecosystem services (ES) approach across the breadth of institutions involved in ecosystem management is the slow integration of terms and concepts across fields. In particular, a distinction between what are termed ‘intermediate’ and ‘final’ ES is widely used in economic and accounting frameworks (Fisher et al. 2008; US EPA [United States Environmental Protection Agency 2009; Ec et al. 2014], yet remains absent from most holistic views of ES (e.g. [MA] Millennium Ecosystem Assessment 2005). Final ES, also known as Final Ecosystem Goods and Services (FEGS; Nahlik et al. 2012; Saarikoski et al. 2015), benefit people explicitly and can be accounted for in biophysical or monetary terms through measures such as fisheries output per season (provisioning ES) or number of lake visitors per year (cultural ES). In contrast, intermediate ES are often described as those ES with little or no direct benefits to people and consist of the biophysical structures and processes that maintain ecosystems in a favorable state for the provision of final ES (correspond roughly to the regulating and supporting ES categories; [MA] Millennium Ecosystem Assessment 2005). Importantly, intermediate ES may not be appreciated unless beneficiaries understand the incentives and benefits of intermediate ES, which may be limited by difficulty understanding complex socioecological

systems, social factors (e.g. educational backgrounds), or spatial disconnections and time lags (Brauman et al. 2007; Sutherland et al. *In Press*). Given the uncertainty behind the intermediate ES terminology, advancing the term will require establishing how the concept has been defined in the past.

Recently, Potschin-Young et al. (2017) have pointed out that the intermediate ES term, which was likely construed by economists, is a catch all concept that is inclusive to all components of an ecosystem that contribute to final ES. The term, they argue, is thus ‘empty’ in the sense that while it may be useful in ecological economics, it has little useful application to describe the ecological phenomenon in ES provision. Meanwhile, other authors have begun to unpack the term with focus toward understanding the ecology of intermediate ES, including how they interact and contribute to ES provision overtime (e.g. Saarikoski et al. 2015; Truchy et al. 2015). The question, as Potschin-Young et al. (2017) emphasize, is not the importance of diverse organisms and ecosystem processes that lead to final ES – that is undisputed – but whether the ‘intermediate ES’ terminology offers any advantages over simply referring to ecosystem functions or ecosystem conditions. A current issue as the ES approach moves into the mainstream is

**CONTACT** Karl A. Lamothe  [karl.lamothe@alum.utoronto.ca](mailto:karl.lamothe@alum.utoronto.ca)

\*Both authors are equally contributed to this article.

 Supplementary data can be accessed [here](#)

© 2018 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

how to align terms and concepts to promote cohesion and operability of the ES framework.

The distinction between intermediate and final ES is pointed out as useful by many authors to operationalize the ES approach (e.g. Nahlik et al. 2012; Saarikoski et al. 2015). For example, focusing on final ES helps establish legitimate endpoints for prioritizing management actions (Nahlik et al. 2012; Saarikoski et al. 2015; Wong et al. 2015). However, although intermediate ES are acknowledged as important for the provisioning of final ES, intermediate ES are typically excluded from economic evaluations to ensure consistent and unbiased evaluations (i.e. to avoid double counting; Boyd and Banzhaf 2007; Fu et al. 2011; Johnston and Russell 2011; Ec et al. 2014). A consequence of the focus on final ES is that the term ‘intermediate ES’ remains undefined compared with final ES, which are defined by more precise criteria (Fisher et al. 2009; Johnston and Russell 2011; Nahlik et al. 2012).

Intermediate ES, or what they are intended to represent, contribute to ecosystem resilience and support the sustained provision of final ES (e.g. Biggs et al. 2015; Truchy et al. 2015). However, until the concept is given proper context with recognition to how the term has been defined across respective disciplines, the value of this concept cannot be fairly examined. A narrative on the origin and meaning of the term could help clarify the intermediate ES concept and set a foundation for examining the term’s applicability for future ES frameworks and science. As such, our goal is to first describe existing definitions of intermediate ES. After reviewing the ‘intermediate ES’ term in published literature, we develop a narrative explaining the disciplinary development, definitions, and use of the term overtime. To further distinguish the term, we discuss it in relation to similar terms such as ecosystem function and ecosystem conditions. We also provide examples of how intermediate ES could be defined in management contexts where multiple ecological processes interact overtime to influence final ES. In particular, we examine the relevance of intermediate ES in a dynamic forested landscape of western North America for sustaining socially desired final ES from aquatic ecosystems. This case study highlights the importance of local context for understanding how and which intermediate ES contribute to the resilience of final ES over time. Finally, we summarize and define key aspects of intermediate ES for further use in ES science.

## 2. Methods

To develop a narrative around the meaning, nuances, and disciplinary origins of the intermediate ES terminology, we reviewed literature mentioning ‘intermediate ES’ or ‘intermediate services’ from 2000 to

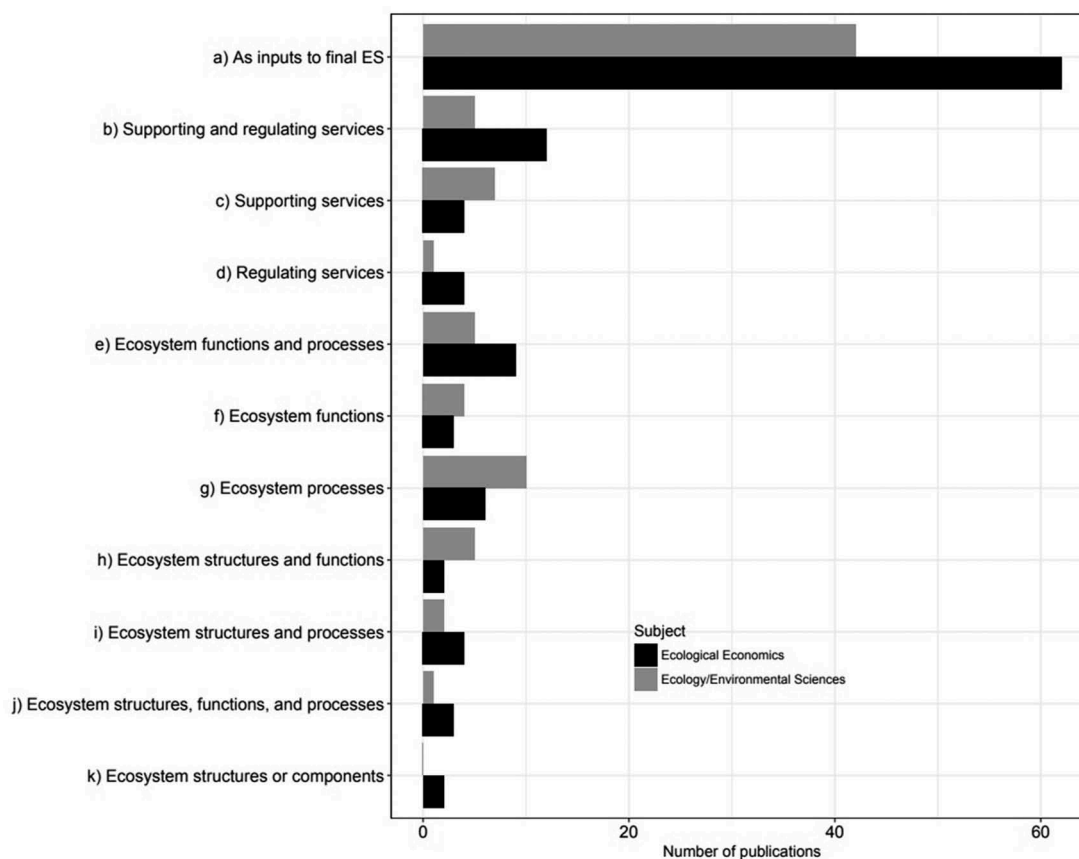
2016. All eligible studies were included from working papers, technical reports, theses, book chapters, conference proceedings, and journal articles (Pullin and Steward 2006). Because major efforts to consistently define ES began in the early 2000s during the [MA] Millennium Ecosystem Assessment (2005), we restricted our search to publications from 2000 to June 2016. We performed three separate searches using the Thomson Reuters Web of Science® Interdisciplinary database: (1) ‘intermediate ecosystem services’, (2) ‘intermediate services’, and (3) ‘ecosystem services’ AND ‘intermediate’. These searches yielded 209 publications. In addition, we used the first 100 hits on Google Scholar® (Milcu et al. 2013; Howe et al. 2014) for the search ‘intermediate ecosystem services’ as well as the first 100 hits for the term ‘intermediate services’. After removing 92 duplicated results, 317 publications remained that mentioned some form of the term ‘intermediate services’ or ‘intermediate ecosystem services’ (See Supplementary Material for a full list).

The 317 publications were then screened for relevance based on the subject of ES and second to assess whether the publication provided at least one definition of intermediate ES. Studies irrelevant to ES were dropped from the analyses. Additional sources were added where studies cited previously published definitions of intermediate ES (i.e. snowball method). Examples of studies that used the ‘intermediate services’ terminology, but were not related to ES and, therefore, dropped from further analyses, primarily included articles that used the term outside of an ecological context (e.g. mental health, internet banking).

In the end, 131 publications relevant to ES were retained, consisting of 91 journal articles, 22 reports, eight conference proceedings, five books, three working papers, and two theses (See Supplementary Material for a full list). We then developed a matrix detailing the 131 retained publications’ respective discipline (economics, ecological economics, ecology/environmental sciences, or other), publication type (e.g. journal, working paper), and year of publication. From each of the readings, we extracted definitions of intermediate ES and grouped them by the following analogies: (1) by the type of pathway that intermediate ES generate benefits (i.e. direct versus indirect), (2) through analogy to the [MA] Millennium Ecosystem Assessment (2005) categories of regulating ES and supporting ES, or (3) as ecosystem characteristics, including ecosystem processes, structures, and functions.

## 3. Results

Few publications provided explicit definitions of ‘intermediate ES’; instead, many ( $n = 110$  publications) used one or more analogies to define the term. Nearly all studies that defined intermediate ES



**Figure 1.** Total number of publications by discipline (ecology/environmental sciences versus economics) by the types of analogies they used to describe intermediate ES.

described them as inputs for producing final ES (104 of 110 studies; [Figure 1\(a\)](#)) 56 publications defined intermediate ES using an analogy to the characteristics of ecosystems that underlie ES provision ([Figure 1\(e–k\)](#)). For example, Johnston and Russell (2011; pp. 2244) defined intermediate ES as the ‘conditions or processes that only benefit humans through effects on other, final services’. Febria et al. (2015; pp. 29) defined intermediate services in relation to ecological production functions, as ‘biophysical processes, ecosystem attributes, and other factors important to the delivery on an ecosystem service’. In total, 33 publications defined intermediate ES by way of analogy to the [MA] Millennium Ecosystem Assessment (2005) supporting services ( $n = 11$ ; [Figure 1\(c\)](#)), regulating services ( $n = 5$ ; [Figure 1\(d\)](#)), or more commonly as regulating and supporting services together ( $n = 17$ ; [Figure 1\(b\)](#))

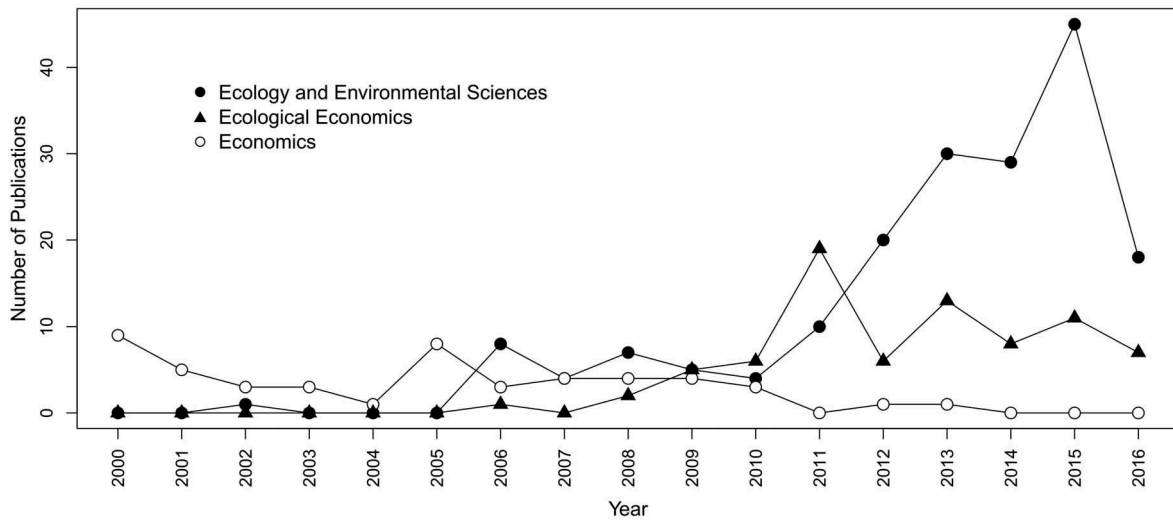
### 3.1. Origins of intermediate ES terminology

The term ‘intermediate services’ originated from the field of economics but recently has been almost exclusively used in ecology and environmental sciences ([Figure 2](#)). From our literature search, the majority of pre-2006 studies were in economics (33 of the 47). The intermediate ES concept became more frequent in the field of ecological economics in 2007.

By 2012, use of the term was greatest in ecology and environmental sciences ([Figure 2](#)).

The ‘intermediate services’ term derived from the economic concept of ‘intermediate goods and services,’ which are the goods and services that go into the production of other goods, including final goods (e.g. Benjamin and Diao 2000). This concept entered ES terminology via studies that considered that there are numerous ecological processes that underpin agricultural and forestry goods; for example, Campos et al. (2001) used the analogy that biomass production and nutrient cycling are required inputs to the final goods in agriculture (i.e. tons of grain yielded) and forestry (i.e. cubic meters of timber).

Overall, we observed a marked increase in use of the intermediate ES term following the [MA] Millennium Ecosystem Assessment (2005) and key papers in ecological economics, which bridged the term more formally into ES terminology. Boyd and Banzhaf (2007; pp. 619) reasoned that ES are limited to the ‘components of nature, directly enjoyed, consumed, or used to yield human wellbeing’; hence, anything that did not yield direct benefit for people, including most supporting and regulating ES, did not qualify as ES. Fisher and Turner (2008) challenged that intermediate components of ecosystems were, in fact, ES because they impact human well-being (albeit indirectly), and later Fisher et al. (2008)



**Figure 2.** Changes in the number of ecosystem services publications using the term ‘intermediate ES’ overtime and by discipline ( $n = 317$ ). \*Note only publications available up to June 2016 were included.

recommended the qualifiers of ‘intermediate’ and ‘final’ services. These and following publications converged with a case for distinguishing between intermediate and final services to avoid double counting, while still acknowledging the importance of intermediate ES for the production of final ES. At the time, however, definitions for intermediate ES were left vague. As such, components of ecosystems that contribute benefits, but do not meet the criteria of final ES, typically fall into the ‘intermediate ES’ group. Until recently, few formal attempts have been made to define intermediate ES (but see Atkins et al. 2011; Potschin et al. 2014; Duncan et al. 2015; Saarikoski et al. 2015; Jiang et al. 2016; Czucz and Condé 2017). Use of the intermediate ES term is increasing, especially in ecology and environmental sciences and was most frequent in the final full year of our census (2015; Figure 2).

#### 4. Discussion

Results from our literature review support our hypothesis that intermediate ES are often defined by exclusion from the final ES category; few detailed or explicit definitions exist for intermediate ES (but see Atkins et al. 2011; Duncan et al. 2015; Saarikoski et al. 2015; Jiang et al. 2016). Most often, intermediate ES are framed as ecosystem components that benefit people indirectly by acting as inputs to final ES provision. However, in this use, ‘intermediate ES’ is, indeed, a catch-all concept that extends across the full suite of ecosystem components and processes involved in final ES provision (Potschin-Young et al. 2017). In practice, intermediate ES have been more commonly defined by exclusion from the final ES category.

Recently, Potschin-Young et al. (2017) suggested that use of the intermediate ES term should be

limited to accounting purposes. For the broader ES literature, they suggest using either ‘ecosystem function’ or ‘ecosystem condition’ to describe the underpinning elements that constitute the provisioning of ES. In this sense, ‘ecosystem functions’ describe the functional characteristics of ecosystems arising from the movement of organisms, material, and energy that lead to final ES provision. Meanwhile, the term ‘ecosystem condition’ describes the characteristics of ecosystems at a given time period (i.e. ‘available stocks’) that influence ecosystem capacity to provide ES (Tomscha et al. 2016). Based on our results and considering emerging ES concepts, we advocate that in most cases, intermediate ES are more aligned with the term ecosystem functions than ecosystem conditions.

However, intermediate ES must be further defined by more specific criteria. Intermediate ES are a subset of ecosystem functions, which maintain, moderate, or recover ecosystem conditions toward favorable states for final ES provision. By definition of being an ES, they must lead in an identifiable way toward opportunities for humans to derive benefits or maintain or enhance well-being. Saarikoski et al. (2015) illustrate the connections between ecosystem functions and human benefits by way of mapping out linkages between important intermediate ES and final ES, using the ecosystem services cascade model.

##### 4.1 Ecosystem service cascade

Our observation that use of the intermediate ES term has increased in ecology and environmental science studies suggests that progress is underway linking the economic term into a broader ecological framework. A conceptual advancement in linking ecology and ES economic frameworks is the ecosystem cascade model (Haines-Young and Potschin 2010). This

model lays out a production chain analogy to view ES provision as dependent on presence of both an ecosystem that can potentially generate ES and the final users who will derive benefits from the ecosystem.

Saarikoski et al. (2015) view that the intermediate ES concept is compatible with the ES cascade conceptual framework. In the view of Saarikoski et al. (2015), intermediate ES are ecosystem structures, processes, and functions specifically defined with the criteria that they lead in identifiable ways to support final ES provision given a particular social context. The intermediate ES term can then be seen to supersede ambiguity over the term ecosystem function and carry a clearer meaning in policy and management contexts to convey the important (yet indirect) contributions of ecosystem functions to human well-being. In an ecosystem planning context, the intermediate ES with key contributions to final ES can then be identified, prioritized, and communicated to the public according to their level of importance for contributing to final ES.

Determining the pathway and importance of intermediate ES to final ES provision will likely require local ecosystem knowledge and consideration of local management objectives (Martinez-Harms et al. 2015). Therefore, the term may have greater applicability at local to regional scales where the influence of various ecosystem characteristics on the benefits people derive from ecosystems can be most accurately assessed.

#### **4.2 Linkages to the millennium ecosystem assessment terminology**

Our finding that researchers often consider intermediate ES as synonymous with regulating and supporting ES is cause to examine the transferability of definitions from the [MA] Millennium Ecosystem Assessment (2005) categories (supporting and regulating services) to the intermediate ES terminology. Examining the theory surrounding these MA categories can yield insight into the complex pathways and specific contexts through which intermediate ES contribute to human well-being. In particular, the interactions and synergies among intermediate ES bundles that lead to the provision of benefits to society may be key to managing final ES, yet are little explored in ES research.

In comparison to 'intermediate ES', the [MA] Millennium Ecosystem Assessment (2005) supporting and regulating ES concepts have been much more thoroughly examined and consistently defined. For example, it is established that the contributions of regulating ES to human well-being are highly context-dependent. Regulating ES can benefit people directly by reducing risks to human safety (e.g. by reducing flood risk) or indirectly by maintaining

ecosystem conditions in favorable states for the provision of final ES (Sutherland et al. In Press).

Theory that examines when and where regulating ES generate benefits is transferable toward an understanding of how intermediate ES link with human well-being (Polasky and Segerson 2009; Sutherland et al. In Press). Regulating ES mediate movements of energy and materials such as by retaining nutrients or holding soil in place from being washed downstream where they can cause undesirable impacts (Haines-Young and Potschin 2013; Mitchell et al. 2015). Hence, benefits accrue from regulating ES only given the presence of a pressure, such as a storm, contaminant, or invasive species that may lead to undesirable outcomes for provision of final ES or direct risks for human safety. Regulating ES may be a high priority for management *in situations* where regulating ES contribute to human safety (e.g. flood risk prevention). This type of regulating ES should be considered as a final ES because it carries direct benefits for human well-being. Other types of regulating ES carry indirect benefits through sustaining ecosystem conditions in a state favorable for final ES or by reducing costs associated with compensating for lost regulating ES (e.g. through water filtration and flood prevention infrastructure; Sutherland et al. In Press). Identifying the value of these latter types of regulating ES requires consideration of landscape contexts, including identifying social needs, potential risks or pressures, and time lags that may obscure the importance of regulating ES (Sutherland et al. In Press).

Recently, landscape indicators and models for measuring regulating ES demand have become available (Barquín et al. 2015; Sutherland et al. In Press) and appear to be transferable toward understanding how the intermediate ES term could be useful to set priorities in ecosystem planning and management. Hence, we advance the definitions for intermediate ES by adding that intermediate ES are highly context-dependent and that identifying intermediate ES requires consideration of both social and ecological factors within a given landscape. Key factors to consider are: what are the final ES desired? what pressures and constraints in a given context may interfere with final ES or human safety? and what, if any, integral ecosystem functions or processes may help ensure reliability of final ES overtime? These factors may require consideration of varying spatial and temporal scales, such as functions that operate across large watersheds (e.g. water purification) and long timeframes (e.g. 100-year floods). Sets of intermediate ES can then potentially be established, defined, and prioritized.

We found that intermediate ES were more commonly defined as supporting ES (Figure 1(c)) than they are as regulating ES (Figure 1(d)). Supporting ES

are the processes that underpin many of the regulating functions, such as nutrient uptake by plants to regulate nutrient levels ([MA] Millennium Ecosystem Assessment 2005). The use of the 'supporting ES' category has declined overtime as authors have argued that the term ecosystem processes should be used in its place (e.g. TEEB 2010; Haines-Young et al. 2017). In this reflection, there is a cause to remember that ES terminology can and should be periodically reviewed, and if appropriate, abandoned. However, before equating intermediate ES too closely with supporting ES, our finding of the diversity of analogies used to define intermediate ES may also speak to the need to clarify key patterns underlying the complexity of ES provision, in general. From an ecological perspective, there are bundles of regulating and supporting ES interacting together across spatial and temporal gradients and these interactions, together, govern ecosystem conditions through time. Overtime, supporting ES influence the evolution of biotic communities, landscape dynamics, and other environmental qualities of interest to biodiversity and human well-being such as levels of fisheries productivity, forest growth, and maintenance of downstream environmental conditions (Kremen and Ostfeld 2005; Luck et al. 2009; Parrot and Meyer 2012; Beier et al. 2015). In cases where impacts from disturbances accumulate overtime, such as in aquatic ecosystems, there are both regulating ES that mediate downstream movement of pressures as well as supporting ES that maintain and repair impacted ecosystem structures (Brauman et al. 2007; Pert et al. 2010). Given that the spatial complexity and time lags in ES interactions are a challenging but important area of ES research (Andersson et al. 2014; Sutherland et al. In Press), future work may benefit from retrospective evaluations of how the collaborative work of key supporting and regulating ES have led to sustainable outcomes for final ES provision.

#### **4.3 Elucidating intermediate ES: an example from coastal temperate forests of western North America**

The aquatic ES provided by coastal temperate forests of western North America, which stretch from northern California to southern Alaska, provide an illustrative case study toward understanding the role of ecological complexity and local context in deciding what to define as intermediate ES. In these systems, final ES are greatly influenced by pressures from forest harvesting disturbances, which counteract natural forest growth patterns that tend to develop into old-growth forest ecosystems (Beier et al. 2015; Sutherland et al. 2016a). Forest harvesting became a widespread disturbance in the mid-1800s, due to increasing settler populations and connectivity to

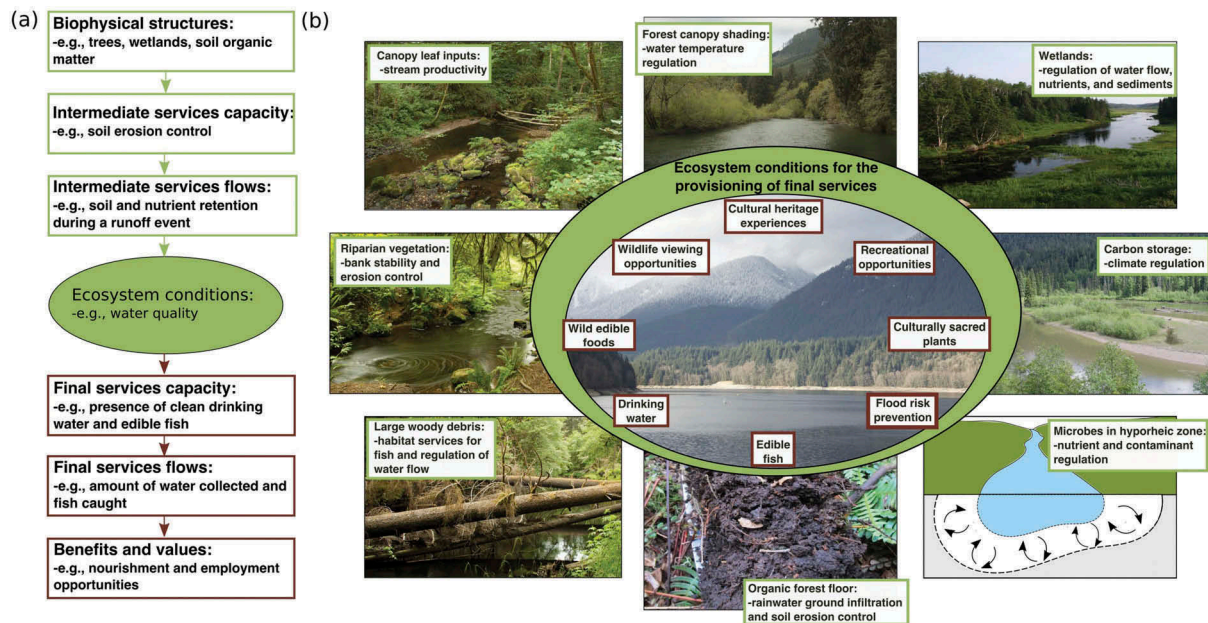
foreign timber markets. Clear-cutting was generally used for harvesting timber, which involves the felling and removal of all trees from a site. Prior to modern regulations, this often included clear-cutting through streamside riparian forests. These forestry practices dramatically altered the structure and function of riparian forests, impairing their ability to harbor some native wildlife species and provide final ES.

Aquatic and riparian forest ecosystems are hot-spots for multiple final ES (Sutherland et al. 2016b). They are culturally valued as locations for recreational and traditional aboriginal fisheries, and as habitat for emblematic wildlife and outdoor recreational experiences. Several species of salmon exist in these waters, such as Coho Salmon (*Oncorhynchus kisutch*), which find habitat in the pools formed from large woody debris of fallen trees (Mellina and Hinch 2009). Additionally, the region's valley-bottom forests tend to have the highest productivity, with the largest heritage trees, richest timber stocks, and highest carbon stores (Smithwick et al. 2002).

Figure 3(a) provides an example of the ES cascade framework adapted to highlight the presence of upstream intermediate ES sustaining downstream final ES. This idea is expanded in Figure 3(b) to highlight that there are likely numerous ecosystem functions and processes that interact in synergy to promote favorable conditions for final ES. Identifying the key bundle of intermediate ES in Figure 3(b) requires identifying which final ES are most desired by local people and then understanding the environmental factors that may promote or hinder final ES supply.

Across the coastal temperate forest range, there are diverse social-ecological contexts, with varying human populations and levels of disturbance. Different economic opportunities and reliance on local provisioning ES (e.g. fishing and hunting) influence the type of final ES desired from the landscape. For example, where drinking water may be a final ES desired from local watersheds in northern California, timber provision may be a primary objective from the land base in rural southeast Alaska. In the California context, preserving water quality may require watershed-scale management that maintains erosion control and nutrient regulation. In Alaska, forest recovery and growth processes may be key intermediate ES to safeguard or enhance. These contexts are integral to consider before defining what may constitute local intermediate ES.

Some ecosystem processes are recognized as having particularly important functions for final ES, and may be considered intermediate ES throughout much of the coastal temperate forests. For instance, in landscapes managed for timber production, forest growth productivity is an ecosystem function of clear importance as it underlies recovery of multiple other ES,



**Figure 3.** Conceptualizing multiple intermediate ES in the ES cascade to identify the indirect pathway through which intermediate ES benefit people. (a) A simplified pathway showing that the biophysical structures and processes of an ecosystem underlie intermediate ES capacity (green boxes). These in turn maintain ecosystem condition for the provisioning of final ES (brown boxes), which directly benefit society. (b) When applying this pathway to aquatic ecosystems, bundles of intermediate ES (green boxes) maintain ecosystem conditions of downstream areas so that they continue to provide final ES (brown boxes).

including timber and carbon storage (Beier et al. 2104). Forest productivity may be considered an intermediate ES throughout most of the coastal temperate forests. Meanwhile, a more nuanced and local understanding of some place-based intermediate ES importance requires consideration of local forest ecology, and how various structures and processes maintain the condition of ecosystems in a favorable state for final ES provision overtime. For example, living and dead vegetation help maintain the condition of aquatic ecosystems. The trees, fallen logs, and understory shrubs physically stabilize river banks, regulate stream temperatures, and provide canopy litter (leaves and other detritus) that act as a nutrient subsidy for nutrient-poor streams (Yeung et al. 2017). In streams where salmon are a desired final ES, the fallen logs that create habitat pools by obstructing water flow and routing sediment may constitute an important intermediate ES (Naiman et al. 2000). Also, in the context of restoring riparian forests that were historically damaged, the large fallen logs and streamside vegetation are often a key intermediate ES to communicate to the public and prioritize in management. These examples highlight the need for often extensive local knowledge for identifying intermediate ES pathways and the importance of intermediate services for providing final ES. For these reasons, the term's applicability may vary from one scale to the next. Operationalizing the term will require scale-consciousness frameworks that establish criteria toward identifying specific intermediate ES at local scales (e.g. habitat for locally desired fish populations) and

general intermediate ES at much larger scales (e.g. carbon storage for global climate regulation).

## 5. Conclusions

Communication is an impetus and important aspect of the ES approach. To clarify the intermediate ES concept and explore its use in existing ES frameworks, we reviewed the meaning of the 'intermediate ES' term. The term originated in economics but is now becoming more frequent in ecology and environmental science publications. Previously, intermediate ES were vaguely defined; analogies in the literature refer to them as ecosystem components, regulating and supporting ES, and as the indirect benefits of ecosystems that contribute to final ES provision. Our results strongly support that intermediate ES have been more commonly defined by their exclusion from the final ES category.

In the interest of increasing operability of the term, we summarize that intermediate ES are ecosystem functions that carry important positive contributions toward human well-being through indirect pathways, which we illustrate using the ecosystem cascade conceptual framework. Measuring 'importance' to determine intermediate ES will often require consideration of local contexts, and sometimes extensive knowledge of how ecosystems and ecosystem changes will influence human well-being. Borrowing from the [MA] Millennium Ecosystem Assessment (2005) regulating ES terminology, we have established that demand for intermediate ES can be generated where it is understood that an absence of

important intermediate ES may jeopardize human safety and/or sustained provision of final ES. Where multiple final ES and intermediate ES are desired from the landscape, considerable understanding of the local ecology and landscape dynamics would be required to manage trade-offs in ES management (Sutherland et al. 2016a). Therefore, intermediate ES must be placed in a relevant context (often at local scales) depending on the pressures and constraints that stimulate demand for intermediate ES.

A challenge for the ES approach is to build robust frameworks for management and decision-making that put intermediate and final ES on a level playing field. A current trend in ES accounting is exclusion of the intermediate ES term. We caution that dismissing intermediate ES may lead to reduced social-ecological resilience and failed efforts to sustainably manage ES. Robust assessments should identify general intermediate ES (e.g. carbon storage from climate regulation) yet also allow incorporation of local knowledge and ecosystem complexity to help understand important place-based intermediate ES.

By clarifying how the intermediate ES term has been used in the past and setting a foundation for how the term may best serve ES science and management in the future, our review helps address a continued challenge for ES frameworks, which is to account for the complex indirect ecosystems contribute to human well-being overtime. Unifying terms across fields will be critical toward the collaborative process of ensuring a sustainable and resilient supply of ES.

## Acknowledgments

Some theory and examples in this work were inspired by a workshop at the Natural Sciences and Engineering Research Council Canadian Network for Aquatic Ecosystem Services 2015 Annual General Meeting in Sault Ste. Marie, Ontario. We thank EM Bennett, members of the DA Jackson (University of Toronto) and SE Gergel (University of British Columbia) labs, and two anonymous reviewers for thoughtful manuscript reviews. We would also like to acknowledge Bronwyn K. Dalziel, a former member of the DA Jackson lab who passed away tragically in 2016. In addition to providing comments on an earlier version of this manuscript, Bronwyn always demonstrated a love and passion for her research that was contagious to everyone around her.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## Funding

This work was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) Canadian Network for Aquatic Ecosystem Services; under a University of

Toronto Connaught International Scholarship awarded to KA Lamothe; and a NSERC Canada Graduate Scholarship awarded to IJ Sutherland;

## ORCID

Karl A. Lamothe  <http://orcid.org/0000-0001-9875-8204>

## References

- [MEA] Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: scenarios, Volume 2. Washington (DC): Island Press.
- Andersson E, Barthel S, Borgström S, Colding J, Elmqvist T, Folke C, Gren Å. 2014. Reconnecting cities to the biosphere: stewardship of green infrastructure and urban ecosystem services. *Ambio*. 43:445–453.
- Atkins JP, Burdon D, Elliott M, Gregory AJ. 2011. Management of the marine environment: integrating ecosystem services and societal benefits with the DPSIR framework in a systems approach. *Marine Poll Bull*. 62:215–226.
- Barquín J, Benda LE, Villa F, Brown LE, Bonada N, Vieites DR, Battin TJ, Olden JD, Hughes SJ, Gray C, et al. 2015. Coupling virtual watersheds with ecosystem services assessment: a 21st century platform to support river research and management. *WIREs Water*. 2:609–621.
- Beier CM, Caputo J, Groffman PM. 2015. Measuring ecosystem capacity to provide regulating services: forest removal and recovery at Hubbard Brook (USA). *Ecol Appl*. 25:2011–2021.
- Benjamin N, Diao X. 2000. Liberalizing services trade in APEC: a general equilibrium analysis with imperfect competition. *Pac Rev*. 5:49–75.
- Biggs R, Schlüter M, Schoon ML. 2015. An introduction to the resilience approach and principles to sustain ecosystem services in social-ecological systems. In: Biggs R, Schlüter M, Schoon ML, editors. *Principles for building resilience: sustaining ecosystem services in social-ecological systems*. Cambridge: Cambridge University Press; 1–31.
- Boyd J, Banzhaf S. 2007. What are ecosystem services? The need for standardized environmental accounting units. *Ecol Econ*. 63:616–626.
- Brauman KA, Daily GC, Duarte TK, Mooney HA. 2007. The nature and value of ecosystem services: an overview highlighting hydrologic services. *Annu Rev Environ Resour*. 32:67–98.
- Campos P, Rodríguez Y, Caparrós A. 2001. Towards the dehesa total income accounting: theory and operative monfragüe study cases. *Invest Agrar Sist Recur For (Spanish)*. 1–2001:43–67.
- Czúcz B, Condé S. 2017. Note on definitions related to ecosystem conditions and their services based on different glossaries. Technical paper N°4/2017. ETC/BD Report European Environment Agency P. 1–19.
- Duncan C, Thompson JR, Pettorelli N. 2015. The quest for a mechanistic understanding of biodiversity–ecosystem services relationships. *Proc Roy Soc B*. 282:20151348.
- Ec UN, Fao IMF, Oecd WB. 2014. System of environmental-economic accounting 2012 – experimental ecosystem accounting. New York (USA): United Nations.
- Febria CM, Koch CJ, Palmer MA. 2015. Operationalizing and ecosystem services-based approach for managing river biodiversity. In: Martin-Ortega J, Ferrier RC, Gordon IJ, Khan S, editors. *Water ecosystem services: a*

- global perspective. Cambridge : Cambridge University Press; 26–34.
- Fisher B, Turner K, Zylstra M, Brouwer R, de Groot R, Farber S, Ferraro P, Green R, Hadley D, Harlow J, et al. 2008. Ecosystem services and economic theory: integration for policy-relevant research. *Ecol Appl.* 18:2050–2067.
- Fisher B, Turner RK. 2008. Ecosystem services: classification for valuation. *Biol Conserv.* 141:1167–1169.
- Fisher B, Turner RK, Morling P. 2009. Defining and classifying ecosystem service for decision making. *Ecol Econ.* 68:643–653.
- Fu BJ, Su CH, Wei YP, Willett IR, Lü YH, Liu GH. 2011. Double counting in ecosystem services valuation: causes and countermeasures. *Ecol Res.* 26:1–14.
- Haines-Young R, Potschin M. 2010. The links between biodiversity, ecosystem services and human well-being. In: Raffaelli D, Frid C, editors. *Ecosystem ecology: a new synthesis*. Cambridge: BES Ecological Reviews Series; 110–139.
- Haines-Young R, Potschin M. 2013. Common international classification of ecosystem services (CICES): consultation on version 4, August-December 2012. Available online: <http://biodiversity.europa.eu/maes/common-international-classification-of-ecosystem-services-cices-classification-version-4.3>.
- Howe C, Suich H, Vira B, Mace GM. 2014. Creating win-wins from trade-offs? Ecosystem services for human well-being: a meta-analysis of ecosystem service trade-offs and synergies in the real world. *Glob Environ Change.* 28:263–275.
- Jiang B, Wong CP, Cui L, Ouyang Z. 2016. Wetland economic valuation approaches and prospects in China. *Chin Geogra Sci.* 26:143–154.
- Johnston RJ, Russell M. 2011. An operational structure for clarity in ecosystem service values. *Ecol Econ.* 70:2243–2249.
- Kremen C, Ostfeld RS. 2005. A call to ecologists: measuring, analyzing, and managing ecosystem services. *Front Ecol Environ.* 3:540–548.
- Luck GW, Harrington R, Harrison PA, Kremen C, Berry PM, Bugter R, Dawson TP, de Bello F, Díaz S, Feld CK, et al. 2009. Quantifying the contribution of organisms to the provision of ecosystem services. *BioScience.* 59:223–235.
- Martinez-Harms MJ, Bryan BA, Balvanera P, Law EA, Rhodes JR, Possingham HP, Wilson KA. 2015. Making decisions for managing ecosystem services. *Biol Conserv.* 184:229–238.
- Mellina E, Hinch SG. 2009. Influences of riparian logging and in-stream large removal on pool habitat and salmonid density and biomass: a meta-analysis. *Can J For Res.* 39:1280–1301.
- Milcu AI, Hanspach J, Abson D, Fischer J. 2013. Cultural ecosystem services: a literature review and prospects for future research. *Ecol Soc.* 18:44.
- Mitchell MGE, Suarez-Castro AF, Martinez-Harms M, Maron M, McAlpine C, Gaston KJ, Johansen K, Rhodes JR. 2015. Reframing landscape fragmentation's effects of ecosystem services. *Trends Ecol Evol.* 30:190–198.
- Nahlik AM, Kentula ME, Fennessy MS, Landers DH. 2012. Where is the consensus? A proposed foundation for moving ecosystem service concepts into practice. *Ecol Econ.* 77:27–35.
- Naiman RJ, Bilby RE, Bissoon PA. 2000. Riparian ecology and management in the Pacific Coastal Rain Forest. *Bioscience.* 50:996–1011.
- Parrot L, Meyer WS. 2012. Future landscapes: managing within complexity. *Front Ecol Env.* 10:382–389.
- Pert PL, Butler JRA, Brodie JE, Bruce C, Honzák M, Kroon FJ, Metcalfe D, Mitchell D, Wong G. 2010. A catchment-based approach to mapping hydrological ecosystem services using a riparian habitat: a case study from the Wet Tropics, Australia. *Ecol Complex.* 7:378–388.
- Polasky S, Segerson K. 2009. Integrating ecology and economics in the study of ecosystem services: some lessons learned. *Annu Rev Resour Econ.* 1:409–434.
- Potschin M, Haines-Young R, Heink U, Jax K. 2014. OpenNESS Glossary (V2.0). Grant Agreement No 308428. Available online: <http://www.openness-project.eu/library/reference-book>.
- Potschin-Young M, Czúcz B, Liqueste C, Maes J, Rusch GM, Haines-Young R. 2017. Intermediate ecosystem services. Empty Concept? *Ecosyst Serv.* 27:124–126.
- Pullin AS, Steward GB. 2006. Guidelines for systematic review in conservation and environmental management. *Conserv Biol.* 20:1647–1656.
- Saarikoski H, Jax K, Harrison PA, Primmer E, Barton DN, Mononen L, Vihervaara P, Furman E. 2015. Exploring operational ecosystem service definitions: the case of boreal forests. *Ecosyst Serv.* 14:144–157.
- Smithwick EAH, Harmon ME, Remillard SM, Acker SA, Franklin JF. 2002. Potential upper bounds of carbon stores in forests of the Pacific Northwest. *Ecol Appl.* 12:1303–1317.
- Sutherland IJ, Bennett EM, Gergel SE. 2016a. Recovery trends in multiple ecosystem services reveal non-linear responses and long-term tradeoffs from temperate forest harvesting. *For Ecol Manage.* 374:61–70.
- Sutherland IJ, Bennett EM, Gergel SE. 2016b. Seeing the forests for its multiple ecosystem services: indicators for cultural services in heterogeneous forests. *Ecol Indic.* 71:123–133.
- Sutherland IJ, Villamagna AM, Ouellet Dallaire C, Bennett EM, Chin ATM, Yeung ACY, Lamothe KA, Tomscha SA, Cormier R. *In Press*. Undervalued and under pressure: a plea for greater attention toward regulating ecosystem services. *Ecol Indic.* 10.1016/j.ecolind.2017.06.047.
- TEEB. 2010. *The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations*. Edited by Pushpam K. Earnscan, Washington DC. pp. 410.
- Tomscha SA, Sutherland IJ, Renard D, Gergel SE, Rhemtulla JM, Bennett EM, Daniels LD, Eddy IMS, Clark EE. 2016. A guide to historical data sets for reconstructing ecosystem service change over time. *Bioscience.* 66:74–762.
- Truchy A, Angeler DG, Sponseller RA, Johnson RK, McKie BG. 2015. Chapter two – linking biodiversity, ecosystem functioning and services, and ecological resilience: towards an integrative framework for improved management. *Adv Ecol Res.* 53:55–96.
- US EPA [United States Environmental Protection Agency]. 2009. Valuing the protection of ecological systems and services: a report of the EPA science advisory board. Washington DC (USA).
- Wong CP, Jiang B, Kinzig AP, Lee KN, Ouyang Z. 2015. Linking ecosystem characteristics to final ecosystem services for public policy. *Ecol Lett.* 18:108–118.
- Yeung ACY, Lecerf A, Richardson JS. 2017. Assessing the long-term ecological effects of riparian management practices on headwater streams in a coastal temperate rainforest. *For Ecol Manage.* 384:100–109.