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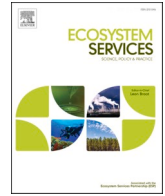
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Short Communication

How ecosystem services are co-produced: a critical review identifying multiple research framings

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ABSTRACT

How ecosystem services are produced remains a critical research gap that must be addressed if services are to persist under on-going and future environmental change. Interest in this area is coalescing under the term 'co-production', which recognises that services are generated through interactions between social and ecological processes. Here we conduct a critical review of academic research into the co-production of ecosystem services, aiming to understand the foundations of this emergent field. Despite its recent origins, we identify four different framings as to how ecosystem services are co-produced and discuss their different epistemological bases and applications. The four framings are: *input focused*, which identifies and measures the inputs underpinning co-production; *actor focused*, understanding who is involved in co-production; *context focused* that situates co-production in social relations and place; and a more disparate *disciplines focused* approach, which highlights alternative conceptualisations of co-production based on diverse disciplinary and conceptual perspectives. There is overlap and dialogue between the four approaches, and we identify examples of how and where to operationalise these framings together to achieve a more holistic understanding of co-production processes. Nevertheless, behind these different framings are differences over what is or is not considered co-produced, and thus what is considered a valid field of inquiry within co-production research. This indicates ontological differences on the social construction of ecosystem services and the role of people therein. We argue that diversity in co-production research is important for representing the complexity of human-environment interactions, but that a more explicit acknowledgement of the ontological assumptions underpinning co-production is crucial if this area of research is to be analytically useful for the management of current and future ecosystem services.

1. Introduction

There is comparatively little understanding of the social and ecological interactions that underpin ecosystem services, which limits our ability to manage them for the future (Bennett et al. 2015; Fedele et al. 2017). Co-production of ecosystem services is often used as a shorthand for the combinations of social and ecological components and relationships underpinning service creation and delivery. The term 'co-production' recognises ecosystem services as dependent "on the joint contribution of nature and anthropogenic assets" (Díaz et al. 2015, p. 6),

and social processes of agency, value attribution and recognition (Fedele et al. 2017; Fischer & Eastwood, 2016; Spangenberg et al. 2014a). Production does not necessarily imply intention. The transformation of ecosystem functions and processes into concomitant services can be achieved either intentionally or unintentionally, capturing different types of feedback between people and the biosphere (Depietri et al. 2016).

'Co-production', in the context of co-producing services and benefits, has been adopted in the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) conceptual framework

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(Díaz et al. 2015) and is growing in use in the literature (Kachler et al. 2023). Ecosystem services refer to the outcomes and processes through which ecosystems contribute to human wellbeing (Costanza et al. 2017; Millennium Ecosystem Assessment, 2005) and under the IPBES process, these contributions have also been referred to as Nature's Contributions to People (NCP; Díaz et al. 2015). Whilst there are differences in framing between ecosystem services and NCP (Kadykalo et al. 2019), both are anthropocentric frameworks (Kenter, 2018; Muradian & Gómez-Baggethun, 2021), which recognise these contributions as contingent on social and ecological processes that interact and operate in combination (Díaz et al. 2015; Haines-Young & Potschin, 2010). For simplicity we refer to the 'co-production of ecosystem services', but our findings also apply to the emerging literature that examines how NCPs are generated.

In this paper, we review what are likely to be the foundations of an emerging area of inquiry into the co-production of ecosystem services. We aim to 1) identify patterns in academic research into the co-production of ecosystem services; 2) examine what characterises different possible strands of this research; and 3) discuss the implications for future work. From this review, we identify four distinct, but overlapping, research framings under the banner of ecosystem service co-production. We name and describe these four framings with examples from the literature, and examine the epistemological approaches that underpin them, and the research applications to which they are suited. From this analysis, we also identify inconsistencies in what co-production encompasses, and explain this through the different ontological assumptions that underpin ecosystem service research more broadly. We conclude with an example that successfully operationalises multiple framings and an example of why co-production is an important area of inquiry in a changing world, before providing recommendations for future research.

2. Four research framings to ecosystem service co-production

For this Short Communication piece, we conducted a critical review of the published literature in which the authors used the term 'co-production' to describe how ecosystem services are produced. Critical reviews rely on interpreting existing literature in order to produce a synthetic overview of a specific body of work. The resulting interpretation is necessarily subjective and forms a starting point for further research (Grant & Booth, 2009). As we sought to review the development of ecosystem service co-production, we constrained our literature search to the academic literature that explicitly uses 'co-production' and closely related terms ('co-creation' and 'co-construction'; Fischer & Eastwood, 2016) in the context of how ecosystem services are produced. The literature that formed the basis of this review was identified using the following search terms: ("coproduc*" OR "co-produce*" OR "co-construct*" OR "co-creat*") AND ("ecosystem service*" OR "nature's contribution* to people*"). Searches were conducted in both Scopus and Web of Knowledge and last updated 30th November 2023 (see Supplementary Information for a detailed description of the search method). We recognise that the focus on 'co-production' necessarily excludes wider research into the mechanisms underpinning ecosystem services that do not use this term (e.g. Jones et al. 2016); that our search may not be exhaustive; and that our search also excludes ecosystem service related terms that imply co-production (e.g. landscape services, social-ecological services). Our approach however is consistent with our research aim to identify and characterise patterns within the academic research on ecosystem service co-production and can be complemented by other literature review approaches that examine different aspects of the co-production literature. For example, in a recent systematic review of co-production as a function of natural and non-natural capitals (a specific framing of co-production as we show in Section 2.1.), Kachler et al. (2023) identified 25 empirical studies that examine the natural and non-natural capitals underpinning nature's contributions to people, but only six of these studies explicitly frame their analysis as co-production.

From our search, we identified 88 studies (85 peer reviewed articles,

and three book chapters; Table S1, Supplementary Material) that explicitly refer to the co-production of ecosystem services or NCPs. The number of studies increased over time (from one study in 2005, two in 2010, seven in 2015, 55 in 2020 and 88 as of November 2023; Fig. S1; Supplementary Information). These studies span different focal ecosystems, methods and disciplines but our interest was in how researchers conceptualised and analysed the co-production of ecosystem services. From our reading of these papers, we identified four main research framings that differ in the focal point of their analysis when considering how services are co-produced. We named these framings: *input focused*, *actor focused*, *context focused*, and *disciplines focused* (Table 1). These framings are not mutually exclusive but indicate differences in how we produce knowledge about ecosystem service co-production (epistemological views), why an investigation of co-production is necessary (theoretical perspectives), and differences in the underlying assumptions of what constitutes an ecosystem service (ontological views; Moon & Blackman, 2014).

2.1. Identifying types of input in ES co-production – input focus

Under an *input focus*, analysis of co-production consists of identifying the inputs needed to generate an ecosystem service, where the type and level of input shape the availability, quantity, and quality of the service (Palomo et al. 2016). These inputs are often described as natural and non-natural capital inputs, with the latter including human, social, manufactured, and financial capitals (Kachler et al. 2023; Palomo et al. 2016). Once the types of inputs have been identified, the relative amounts of input can be quantified and analysed mathematically, for example through modelling the effects of different input combinations on service provision (Dang et al. 2018). Where quantitative data on inputs are lacking, relative amounts of input can also be understood qualitatively, described in terms of co-production gradients from the natural to non-natural (Palomo et al. 2016). An understanding of these gradients can then be used to inform the sustainable management of ecosystem services. For example, in the case of five fisheries in Northern Spain and Portugal, Outeiro et al. (2017) identified a gradient of reliance on natural and non-natural inputs needed to sustain the different fisheries. Of the five fisheries studied, each was reliant on non-natural inputs to maintain ecosystem services. Outeiro et al. (2017) argue that large shifts in the types of input needed (e.g. introducing artificial seeding of shellfish in what was a wild harvest fishery) should be monitored, as this can result in trade-offs with other ecosystem services or indicate a possible tipping point in social-ecological system dynamics. Underpinning the input framing of co-production is the assumption that ES can be understood as an output of different types of inputs (sitting within an objectivist epistemology; Moon & Blackman (2014)). Thus, identifying and measuring inputs is sufficient to understand co-production within this focus (Table 1). This research framing can be applied, for example, to compare and contrast co-production across different types of management restrictions in a protected area (Paliwoda et al., 2021) and identify the combinations of inputs needed to sustain different services (Kachler et al. 2023). The input focus is also implied in the IPBES conceptual framework which recognises "anthropogenic assets" in the co-production of NCPs (Díaz et al. 2015), although more recent conceptualisations of life frames (Kenter & O'Connor, 2022; O'Connor & Kenter, 2019; Willemen et al. 2023) adopted by IPBES to help organise its values typology (Pascual et al. 2023) considers broader conceptions of co-production as "people's contributions to nature" (Anderson et al. 2022, pp. 69–70).

2.2. Identifying human actors in ES co-production – actor focus

Analysis of ecosystem service co-production emerged, in part, as a response to the assumption that benefits trickle down from ecosystems to people (Spangenberg et al. 2014a). The apolitical nature of this analogy, and lack of recognition of who carries the costs and benefits,

Table 1

Four research framings identified from existing research into Ecosystem Service (ES) co-production (also applicable to the co-production of nature's contributions to people). These framings are not mutually exclusive but differ in their research foci, epistemic assumptions, and existing applications.

Research framed around	Inputs	Actors	Context	Disciplines
Description	An input model of co-production. Breaks co-production down into the types of human and non-human input underpinning ES.	Identifies and examines the role of different actors (individuals, groups, or institutions) within co-production.	Situates co-production in social relationships and place. Co-production is therefore contextually specific.	Refers to the application of different disciplinary approaches, concepts and/or methods, traditionally located outside of ES research, to examine ES co-production.
Dominant epistemic assumptions	ES can be understood by identifying and measuring inputs.	ES can be understood by understanding how people generate and experience them.	ES can be understood by understanding the context in which they occur.	Diverse
Example applications of framing	Identifying the types of input needed to produce seafood (natural or non-natural capital, including human, social, financial, and technological) can indicate possible unsustainable use, tipping points and trade-offs between different ES (Outeiro et al. 2017).	Identifying who provides labour in ES co-production and situating this in power relations surrounding ES can be used to identify who is exploited and who benefits in ES co-production (Borbés-Blázquez et al. 2016).	Existing uses of urban green spaces and social relationships shape perceptions of safety. These in turn can determine how ecological features translate into ES and wellbeing contributions for local communities in a London urban regeneration project (Juntti & Lundy, 2017).	Building on the concept of co-production and the psychological theory of affordance, Raymond et al. (2018) propose embodied ecosystems as a way of understanding and conceptualising the dynamic relationships underpinning ES.

resulted in a strand of co-production literature focused on how actors (individuals, groups, or institutions) interact to conceive, generate, and access services. This includes, for example, recognising and understanding labour relations in co-production to examine power relations in ecosystem service generation and to achieve a more socially inclusive distribution of benefits (Borbés-Blázquez et al. 2016). This is particularly salient as the interplay between power and the generation of services and values has been ill-considered in the ecosystem services field, particularly in empirical valuation studies (Kenter et al. 2019). Identifying and understanding the role of different actors can also be used to enhance ecosystem service management more broadly. For example, it is possible to identify where gaps in management occur by understanding how actors perceive their role in maintaining services, compared to the role attributed to them by others (Jericó-Daminello et al. 2021). The social context in which these actors contribute to co-production is incorporated to different degrees. Actors can be individuals and their role in co-production analysed as such, but co-production can also be shaped by the collective capabilities of a group (Grosinger et al. 2021). Knowledge of ecosystem service co-production under this research framing is rooted in the assumption that knowledge is constructed by people, with explicit recognition that power is distributed differently between people, and with a disposition to more constructionist or subjectivist epistemologies (Moon & Blackman, 2014; Table 1). As such, this framing is not so different epistemologically from the *context focus* framing (see Section 2.3.) but researchers can choose to operationalise this focus to highlight and challenge injustices or inequalities in ecosystem service co-production, for instance to show where key stakeholders are not included in the relevant governance networks (Barraclough et al. 2022).

2.3. Co-production as situated in social relationships and place – Context focused

Context focused research into ecosystem service co-production is shaped by an understanding of ecosystem services as rooted in the relationships between people, and between people and place, with a greater emphasis on place than in the *actor focused* framing (see Section 2.2.). Central to this approach is the perception that co-production is complex, indivisible and strongly shaped by the specific context in which co-production occurs. Under this framing, physical processes of co-production, for example, the modification of ecological systems to enhance ecosystem service potential (e.g. coppicing) and the mobilisation and appropriation of these services (e.g. harvesting of wood and burning of wood to generate heat), cannot be understood separately from processes of use attribution and meaning making (e.g. perceiving

woodlands, wood and heat as important for personal or community wellbeing) (Fischer & Eastwood, 2016; Spangenberg et al. 2014b). This framing can therefore be used to understand the conditions under which environmental features are translated, or not, into ecosystem services. Juntti & Lundy (2017), for example, identify perceived safety and inequalities – as determined by existing social relations in urban green spaces – as key for shaping future perception and use of ecosystem services in a London borough regeneration project. Much of this work builds on advances in cultural ecosystem services research, where the term ‘co-production’ originated in the context of ecosystem services (Fischer & Eastwood, 2016). The situatedness of co-production processes also extends to recognising ecosystem services as connected to specific environmental settings that are shaped by historical and contemporary human uses (Fish et al. 2016a). Under this framing, knowledge about co-production is highly context specific, reflecting multiple ways in which ecosystem services are co-produced in different social, cultural, historical, and environmental settings. This frame thus predisposes towards more subjectivist epistemologies and interpretivist knowledge perspectives (Moon & Blackman, 2014) (Table 1) and can be applied to develop a deeper level of understanding of co-production, which will be highly specific to the study location (Kochalski et al. 2022).

2.4. Disciplinary perspectives on co-production – disciplines

Ecosystem services research is multi-disciplinary and advances can come from many different perspectives. The *discipline focused* approach takes the idea of co-production at face value – that ecosystem services are both social and ecological in origin – and shines a new light on co-production from a different disciplinary or conceptual perspective. How research under this framing relates to the wider ecosystem services canon is highly variable. For example, Vaz et al. (2018) reframe the cascade framework (Haines-Young & Potschin, 2010) around gastronomy, as an alternative conceptualisation of bundles of ecosystem services, and examine how these services originate from human activities, biophysical and ecological structures, and processes. Moving further from traditional ecosystem service approaches, Raymond et al. (2018) incorporate co-production and psychological theory to propose an alternative conceptualisation of co-production grounded in embodied scientific realism. Research under the *disciplines framing* is used to provoke debate and introduce new ways of thinking to ecosystem management and conservation. This could be an important source of disruptive and novel research, though the challenge will be integrating this literature into the nascent yet already diverse field of ecosystem service co-production research (Table 1). The epistemic

assumptions and applications underpinning this framing are diverse and reflect those of the framework, concept or approach through which co-production is being interpreted.

3. What is and is not co-produced? Different ontological perspectives on the social construction of ecosystem services

Cross-cutting the four research framings under which we clustered existing co-production literature are two ontological views: one grounded in the assumption that ecosystem services can exist independently of people, and the other that they cannot. It should be acknowledged that as an inherently anthropocentric concept ecosystem services, and NCP, will always centre the values ecosystems provide to humans (Kenter, 2018; Muradian & Gómez-Baggethun, 2021). However, these different ontological approaches have implications for what is and is not incorporated into studies of co-production. If ecosystem services can exist without the involvement of people, then conceivably not all ecosystem services are co-produced. This makes it less likely that certain services will be included in co-production research, for example regulating services by Malinauskaitė et al. (2021) in the context of ecosystem services associated with whales. Co-production analysis, in this sense, is limited to direct physical interaction and input in the production of ecosystem services. This is expressed most obviously, but not exclusively, in studies that focus on inputs.

Alternatively, if services cannot exist without the involvement of people, then all ecosystem services are co-produced. Without the attribution of meaning to, and demand for, ecosystem processes and functions, ecosystem services do not exist and should therefore be recognised as a social construct (Barnaud & Antona, 2014; Budds & Zwartveen, 2020). In other words, the social context and relationships through which meaning and importance are established are integral to ecosystem services and thus should be considered as part of co-production. Fischer & Eastwood, (2016) term this ‘co-construction’ of ecosystem services.

The implications of recognising all ecosystem services as co-produced is that the social interactions and context in which services originate are recognised in our understanding of *how* ecosystem services occur and can thus be integrated into their management. Working from the basis that all ecosystem services are socially constructed, the analysis of ecosystem service co-production can provide a powerful tool encompassing all aspects of the ecological and social processes that determine how the biosphere affects human wellbeing. An understanding of co-production as linked to tangible human interventions in ecosystem services is useful (e.g. in sustainability assessments; Outerio et al. (2017)) but should be contextualised as only a partial understanding of co-production.

4. How to, and when to, operationalise multiple framings

We also find examples in the literature that operationalise multiple approaches to co-production. Heinze et al. (2021), for example, explore the co-production of pine resin in Mexico, examining the social-ecological components and interactions that determine services and benefits. They highlight the struggles associated with producing benefits from pine but differentiate between actors in the focal system and actors outside of the focal system. They also highlight how co-production feeds back into wider community wellbeing, as well as pine biology and fire resistance. The emphasis on a bounded or focal social-ecological system supports multi-method approaches that can capture inputs (Section 2.1), actors (Section 2.3), as well as placed-based social relationships that shape values (Section 2.3) and underpin ecosystem services (Table 1).

When to engage with this plurality is highlighted by Bruley et al. (2021) in the context of adapting to changing mountain social-ecological systems. Having the ability to modify ecosystem service co-production over time can actively support social adaptation against a backdrop of climatic and environmental change (Bruley et al. 2021). Examples of co-production processes that support adaptation include

working to sustain specific valued services despite changes in the underpinning ecological units (e.g. through modifying inputs); co-producing latent ecosystem services that support adaptation in response to specific contexts (e.g. flooding); and the production of novel ecosystem services (Lavorel et al. 2020). Novelty does not necessarily imply tapping into new ecological processes (though it is possible with, for example, non-native species; Sax et al. 2022) and includes shifts in the uses, meanings and values from which services and benefits to people are defined (Woodhead et al. 2019). Underpinning all of this is recognising the agency of different actors to modify co-production processes for adaptation (Bruley et al. 2021).

5. Final remarks

In this review we identified four research framings that emphasise different aspects of ecosystem service co-production and that can be applied to different research questions (Table 1). These framings represent epistemological diversity within co-production research and echo a wider acknowledgement that the study of ecosystem services has not matured to consensus (as reviewed by Fish et al., 2016b). It is also important to recognise that, while ‘co-production’ has only been operationalised as a standalone concept for the last 10 years (Fig. S1; Supplementary Information), it builds on a much wider area of inquiry into human-environment interactions. Using the term ‘co-production’ as an entry point for this analysis is thus a strength and a limitation as it necessarily omits wider research that also engages with the social and ecological interactions underpinning ecosystem services. An additional drawback is that the term could perpetuate dualistic worldviews where nature and humans are seen as separate entities, a critique that has been more widely addressed at the concept of ecosystem services. However, we see the plurality of co-production approaches that we have identified – which echoes the plurality of research approaches into the benefits people derive from nature – as a strength that further enables the complexity of human-environment relations to be integrated into an ecosystem service framing. We also see huge potential in the field of ecosystem service co-production for generating novel inter-, multi- and trans-disciplinary understanding of the interactions between the biosphere and human wellbeing in a changing world, providing an opportunity to better include the social and cultural dimensions, and power dynamics, associated with the generation of ecosystem services. Studies that fit under the *discipline focused* framing could in particular be an exciting source of novel and disruptive research, provided that they are then brought together with other articulations to understand co-production in more comprehensive ways. Moreover, the concept of NCP has been shown as particularly useful for engaging with the cultural dimensions of complex social-ecological systems (e.g. Dean et al., 2021) and analysis of co-production of NCP specifically could deepen our understanding of the socio-cultural dimensions of benefit generation.

Key challenges, however, could be associated with the ontological divergence over what is and is not considered co-produced. This could limit synthesis and useability of co-production research in applied contexts, as well as cross-disciplinary learning. As researchers, we align ourselves with the view that all ecosystem services are co-produced through the attribution of value to ecological structures and functions, and acknowledging that people have been physically modifying their environment to their benefit throughout the Holocene, and potentially for millions of years. Rather than recommend a single way forward, we call attention to the plurality of research framings as a strength to be acknowledged and built on, but that this has to be accompanied by a critical acknowledgement of researchers’ ontological assumptions over what is and is not co-produced. This will provide clarity on how different studies contribute to the understanding of co-production, and together, this can form a robust basis for the management of co-production processes to sustain human wellbeing into the future.

CRedit authorship contribution statement

A.J. Woodhead: Writing – original draft, Project administration, Methodology, Formal analysis, Conceptualization. **J.O. Kenter:** Writing – review & editing, Conceptualization. **C.D. Thomas:** Writing – review & editing, Funding acquisition, Conceptualization. **L.C. Stringer:** Writing – review & editing, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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Data availability

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

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