ABSTRACT

Title of Thesis: CO-PRODUCING ENVIRONMENTAL KNOWLEDGE WITH COMMUNITY STAKEHOLDERS

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To generate robust and integrated solutions to complex sustainability problems requires the co-production of environmental knowledge. Co-production focuses on the socio-ecological contexts and knowledge forms of diverse actors in iterative dialogue to collectively generate new knowledge and practices relevant to societal challenges and decision-making. Despite its growing popularity, there remain a range of challenges and structural barriers obstructing the inclusion of local communities and place-based knowledge in co-producing environmental research and management. This thesis presents results from a comprehensive review of the co-production literature in general and focuses in particular on case studies where local environmental knowledge and stakeholders are included within the co-production process. Key findings suggest that additional attention to *institutional capacity constraints,* such as socio-political processes, space, funding,

timing, and facilitation, as well as *power and inclusion constraints, s*uch as representation and knowledge, provide opportunities for increased integration of local environmental knowledge in the co-production process.

CO-PRODUCING ENVIRONMENTAL KNOWLEDGE WITH COMMUNITY STAKEHOLDERS

By

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Introduction

Climate change and other complex, ‘wicked’ problems continue to test the capacity of traditional, ‘loading dock’ models of science and knowledge production that hold researchers as the exclusive purveyors of environmental expertise (Berkes, 2017; Rittel & Webber, 1973). Top-down scientific knowledge generation, and subsequent policy, commonly take a ‘one size fits all’ approach, prioritizing global narratives and consultative, prescriptive practices that resonate little with local communities (Homsy & Warner, 2013). The scope, complexity, and uncertainty of environmental problems, such as climate change, warrant the inclusion of different types and sources of knowledge that capture local challenges and solutions. Participation is a mechanism for connecting science with other ways of knowing, and establishing new ways of knowing that deviate from traditional scientific inquiry (Miller & Wyborn, 2018). Researchers are increasingly employing multi-stakeholder engagement and participatory approaches that transcend traditional research-practice-policy boundaries, ensuring that essential communities of knowledge are being deployed to cooperatively tackle complex sustainability challenges. In doing so, environmental managers, policymakers, community members, and researchers become active participants in developing knowledge that has value and relevance to their surroundings.

When the process is knowledge-driven and interactive, the results reflect both what was necessary to understand complex problems and the

information identified by stakeholders as necessary for decision-making (Lemos & Morehouse, 2005). Stakeholder engagement helps bring to light some of the uncertainties recognized in current research pertaining to a region, while gaining buy-in and support from participants to facilitate the research (Carney et al., 2009). Participatory approaches to knowledge production typically use more transparent processes and information that are inclusive of and tailored to stakeholders, thus this more accessible information enables action. The resulting knowledge is more likely to be accepted and used by decision-makers, as they better understand the process by which it was made, and they feel a greater sense of knowledge ownership (Meadow et al., 2015). Participatory approaches will entail the transformation from society as a passive beneficiary of knowledge into full participants in the co-design and co-production of knowledge (Mauser et al., 2013). Over the past few decades, people-oriented approaches are increasingly being developed for conservation, resource management, climate mitigation and adaptation, and other environmental fields (Brown, 2003).

Place-based and community knowledge represent essential types of knowledge to be engaged in the participatory process, capturing the local condition and strategies for adapting to a changing environment. Participatory approaches to environmental science and management enable the involvement of indigenous peoples and local communities (IPLCs), affording them voice and self-determination in the research and

decision-making processes that govern the highly contested resources upon which they depend. Traditional knowledge, or traditional ecological knowledge (TEK), is both a way of knowing and a place-based process that encompasses local knowledge of species, ecological and climatic conditions, livelihood practices, and cultural beliefs, values and norms (Berkes, 2009b). Scientists and IPLCs can learn from one another in iterative processes of knowledge exchange. For example, traditional ways of knowing are often able to discern longer-term changes as they develop in particular places (Lebel, 2013). Participatory approaches to research and management also contribute knowledge, tools, and relationship-building to enhance local capacity to adapt and mitigate the environmental problems that threaten their livelihoods, identities, cultures, and ways of life.

The concept of co-production has grown in popularity as an interactive, problem-driven model of knowledge production (Mach et al., 2020). Co-production is an iterative process that brings multiple knowledge sources and types together to collectively generate new knowledge and practices for societal challenges, decision-making, and transformative outcomes (Armitage et al., 2011; Wyborn et al., 2019). In the context of environmental work, this participatory process brings to light the socio-ecological contexts and knowledge forms of diverse actors, including policy-makers, scientists, environmental managers, business owners and industry, and community members. Therefore, its practice

provides a space for investigating and changing how decisions are made by transforming who is included in the process of producing knowledge. Co-production is intended to be a reflexive, open-ended, and inclusive process in which every stage features mutual knowledge generation among all stakeholders (Lövbrand, 2011; Tengö et al., 2014). Thus, co-production allows for a more holistic understanding of problems. By collaborating in every stage of the research process, CP dissolves traditional boundaries between ‘producers’ and ‘users’ of knowledge, whereby all types of expertise are considered essential and contribute to knowledge production (Flinders et al., 2016). Co-production endeavors to advance new ways of acting and making decisions by opening spaces for diverse participants to collectively “produce multiple outcomes, including new knowledge, new ways of integrating knowledge into decision making and action, and, most importantly, new outcomes in the world” (Wyborn et al., 2019, p. 2).

The practice of co-production challenges traditional, top-down scientific expertise and universal knowledge claims by offering a more open-ended, reflexive, and inclusionary process of collaboration meant to shed light on new perspectives and old assumptions (Lövbrand, 2011). Co-production seeks to produce not only pluralistic, relevant knowledge for problem-solving, but transformative relationships and the institutional capacity to implement it (Wyborn et al., 2019). Throughout the past several decades, the concept of ‘co-production’ has gained visibility as

both a descriptive, constructivist theory of science and society (Jasanoff, 2004), and a practical process of engaging non-scientists in the production and use of knowledge (Lemos & Morehouse, 2005; Prokopy et al., 2017).

However, as a relatively new, normative concept, the applications and approaches to co-production are muddled, and lack both quantity and variation in empirical case studies tracing what practitioners are doing on the ground (Hegger et al., 2012; Jagannathan et al., 2020; Lemos et al., 2018; Wall et al., 2017). More recently, co-production has taken a utilitarian turn within climate research as a mechanism for generating usable science, that is "science that decision makers seamlessly perceive as fitting their needs and decision environments" (Kirchhoff et al., 2013, p. 396; Lemos & Morehouse, 2005). This scholarship emphasizes co-production as a means for bridging science-policy interfaces, therefore researchers often only engage those in an authoritative position to effect change. By privileging some stakeholders over others, co-production risks excluding local, place-based knowledge and actors. In aspiring to further sustainability and democratize knowledge production, it is contradictory to prioritize the participation, needs and values of politicians and other professionals over the communities to which they serve (Sancino, 2016). If the goal is to generate 'outcomes,' rather than mere 'results,' then the community members must be understood as both knowledge holders and users, decision-makers and action-takers (Lebel, 2013; Sancino, 2016).

More generally, co-production for socio-ecological outcomes entails world-making practices, such as adaptation and resilience, which are complex, ever-changing, and replete with power dynamics (Goldman et al., 2018). Co-production is a boundary-spanning process to engage with a variety of stakeholders and knowledge systems in addressing a given problem and associated plurality of values at stake (Harris & Lyon, 2014). Furthermore, the co-production process, like other forms of knowledge generation, is a social process that occurs within larger socio-political networks, thereby co-production is inherently a political process. Despite its growing popularity, there still remain a range of challenges and structural barriers obstructing the inclusion of local communities and place-based knowledge. In this context, it is critically important to explore whether and how co-production integrates community-based socio-ecological knowledge.

To better understand if and how local knowledge sources and actors are being included, this thesis examines the barriers constraining the co-production process in general, and particularly with local participants. Limitations and tensions arise in relation to institutional demands, funding, siloed mentalities, inclusivity, resource and power distribution, legitimacy, and knowledge integration and exchange. These can be broadly grouped into two categories: (1) institutional capacities, or the institutional contexts and resources affecting the capacity for collaboration and uptake of knowledge; and (2) inclusion and power,

which refers to power relations and inclusion of different knowledge sources, interests, understandings, and values. These represent bottlenecks to the integration of local knowledge, and if not adequately addressed can reinforce the exclusionary practices and siloed modes of knowledge exchange that co-production seeks to counteract. With that said, each of the barriers present both constraints and opportunities for participation by local actors. If addressed, the two challenges transform into avenues for improving co-production in general and its inclusivity.

I first examine the broader co-production literature, 220 articles, to determine its conceptual origins and current applications, which begin to reveal the roots of exclusionary practices that diverge substantially from its theoretical inception. I synthesize 13 co-production articles with 20 case studies that feature community stakeholders across diverse environmental fields to expound the constraints and opportunities for community inclusion associated with its current barriers of institutional capacities, and power and inclusion. The challenges document the obstacles to including and working with communities, whereas the opportunities include insights on conditions, methodologies, and lessons learned to inform the practice of co-production. I argue that by omitting local participants, practitioners effectively sidestep the challenges currently restraining the full transformative and actionable potential of co-production. The 13 co-productive articles report their process and outcomes, including missteps and key practices leading to their success. I synthesize their

methodologies and tools according to the two barriers to highlight how co-production can be inclusive of a plurality of stakeholders for environmental research and management. In synthesizing case studies of co-production projects, I contribute to the growing demand for better understanding the methodologies being used in practice, which can help guide co-production practitioners.

The thesis is organized as follows. First, I introduce the methodology for the review of co-production studies that I conducted. In the subsequent section, 'local knowledge,' I provide a primer on local and traditional ecological knowledge, including what it is and why its holders should be integrated in co-production efforts. In the following section, 'co-production background,' I review the co-production literature to delineate the scholarly origins of co-production and its divergent, yet mutual, conceptual applications. I conclude the section with a review of the approaches, stages, and principles pertaining to co-production in practice, which helps to better understand the nature of the process through which each case study underwent. The subsequent section, 'results,' presents each of the co-production barriers, organized first by the constraints they pose and then the opportunities they present. The constraints and opportunities for engaging and working with communities related to *institutional capacities* include: 1) socio-political, 2) spaces, 3) timing and funding, and 4) facilitation. The constraints and opportunities related to *power and inclusion* are: 1) representation and participation, and 2)

knowledge. I conclude the thesis with a discussion on the insights gleaned from both the literature and case studies, and indicate how co-production practice can better learn from working with communities.

Methods

The initial guiding question for this thesis was broad and open-ended: how is co-production used within environmental studies? As the research progressed, new, more specific questions emerged. One key question that became of importance was the ways in which research and management incorporated local socio-ecological knowledge. A focus on the challenges and opportunities for co-production and local environmental knowledge has added to our insights on how co-production is a promising process for generating an inclusive, immersive research and management collaboration.

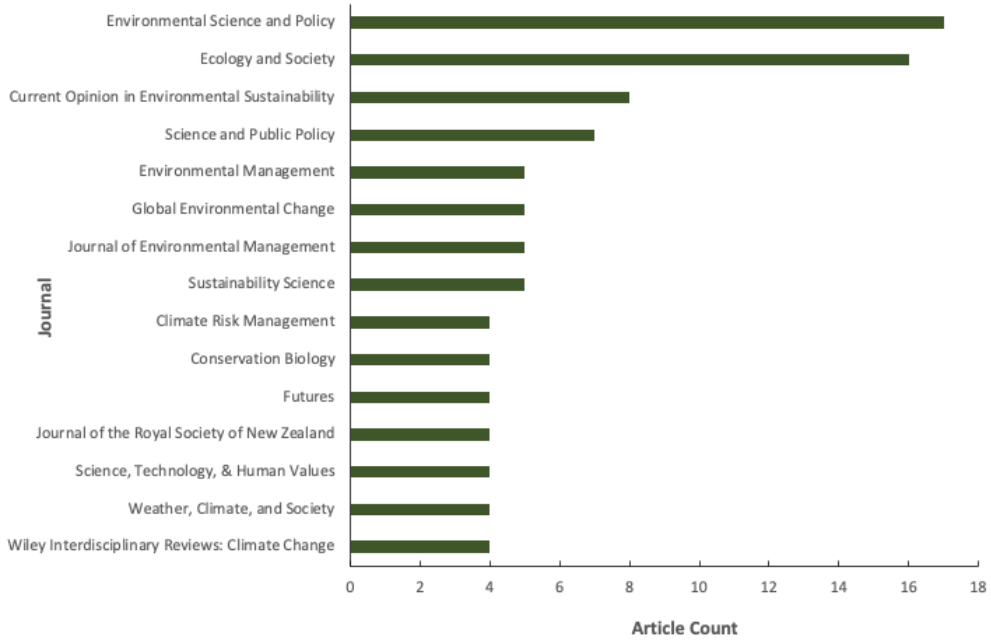
The first part of this thesis consists of a broad literature review on co-production to better understand its history, how it is conceptualized, and its applications within environmental science. During this initial exploratory literature review, the topic and scope of the review remained general to better understand the full picture of co-production within environmental fields. At first, the criteria for inclusion was open-ended; articles needed to discuss co-production, and in some capacity, discuss the environment. Papers from a wide range of journals and fields were included with the stipulation of addressing an environmental component, for example a paper from public services that discussed environmental governance and services was included.

I compiled this literature using general terms and phrases related to co-production within environmental research in Google Scholar and

Worldcat databases. Search terms included variations of “co-production” and other terminology commonly used, including “coproduction,” “co-production of knowledge,” “coproduction of knowledge,” “knowledge coproduction,” “joint knowledge production,” and “collaboration.” These were combined with “environment” and/or related term, such as “environmental management,” “climate,” “sustainability,” “environmental science,” “ecological science,” “adaptation,” “mitigation,” and “natural resource.” In addition to the database search, more widely-cited papers were used to identify additional papers through a process of “snowball sampling” (Lecy & Beatty, 2012) These revealed the historical roots and seminal texts of co-production. In total, I reviewed 220 journal articles, book chapters, and reports. The articles most frequently came from the journals *Environmental Science and Policy* and *Ecology and Society* (Figure 1).

Figure 1

Most Frequently Cited Journals for Co-production References



Note. Number of articles referenced within the literature review corresponding to the most frequently cited journals. Only journals with four or more articles are included.

The initial literature analysis was completed using a deductive scheme of coding with a data analysis software, MAXQDA (Saillard, 2011). First, I coded the text of 50 commonly cited and comprehensive papers to identify how co-production was being applied. This first set of codes included: “co-production definition and characteristics,” “type of co-production,” “history,” “application,” “problem/rationale,” “outcome/finding,” “purpose/methods,” “challenges,” and “guideline” (Figure 3). The analysis revealed the degree of nuance and complexity surrounding the conceptual applications of co-production. I generated a separate list of current gaps based on those identified by literature published between 2009-2019

focusing on co-production as a participatory approach (i.e. Fazey et al., 2012; Beier et al., 2017; Djenontin & Meadow, 2018; Wall et al., 2017; Bremer and Meisch, 2017; Lemos et al., 2018; Cornell et al., 2013). Emerging themes, such as the common steps to co-production, and deficiencies, such as the barriers to co-production, in the literature iteratively guided further problem formulation.

In ensuing months of iterative analysis, common challenges to co-production were identified across both the technical literature and the case studies. It became clear there was a need to identify and analyze how co-production is used to "trace what stakeholders are doing on the ground" (Lemos et al., 2018). Case studies that included discussion of local stakeholders were identified. I followed the approach of Djenontin and Meadow (2018) by exploring how co-production is implemented in the field, but I strove to focus more on specific methodologies for practitioners from a larger pool of projects that specifically included local stakeholders. The analysis of literature made evident that although local priorities were being addressed, decision-makers and politicians were emphasized much to the exclusion of local actors representative of wider society. As a result, a more specific research question emerged asking whether and how co-production integrates community-based socio-ecological knowledge, according to case studies relaying their praxis of co-production.

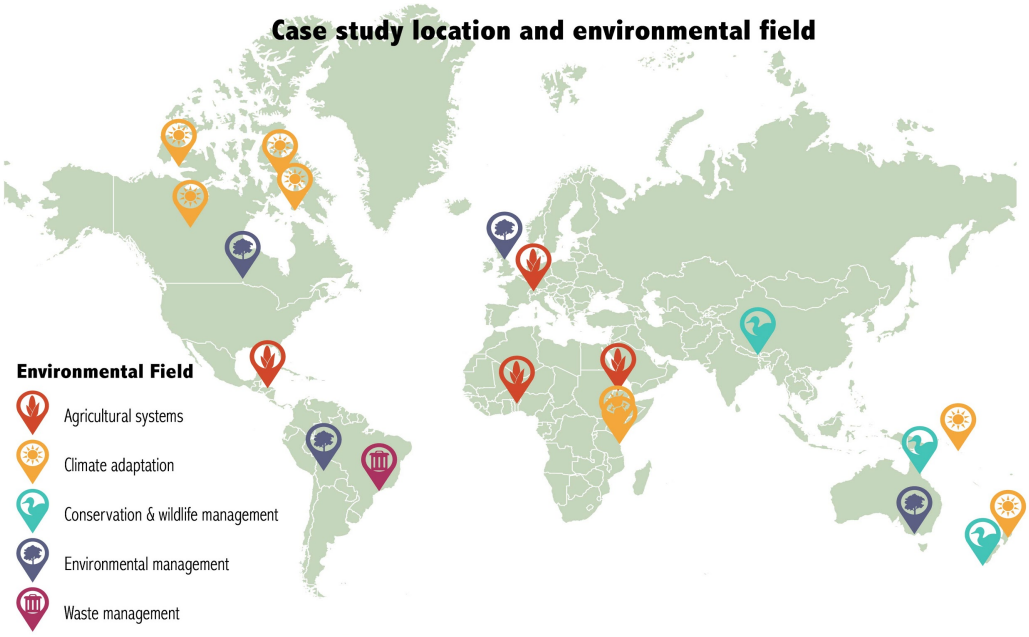
In the subsequent search for "local or community" case studies, the initial criteria for their selection was similar to that of the broader review:

(1) objectives related to broader environmental research or management; (2) includes co-production or a similar collaborative process project; (3) project locations dispersed around the world; (4) featured community stakeholders; and (5) provided a detailed description of their research process and engagement of nonscientists. This resulted in a sample of 31 articles, which I further refined according to their inclusion of community stakeholders. I selected articles that maintained collaborative or collegial engagement with community members throughout the project and reported some successful outcomes. I eliminated articles that mentioned communities only in passing, as well as those that only emphasized the relationships between policymakers or decision-makers and scientists. My search was not sweeping (i.e. zero cases in the United States), as there are undoubtedly papers that emphasize communities under one of the numerous approaches to co-production. This further resulted in 13 articles with 20 case studies that took part in a co-production process with communities for environmental research or environmental management objectives. The case studies did not all specify “co-production,” but those that did not used a co-production approach (action research, transdisciplinarity, participatory integrated assessment, and rapid assessment process) as defined by Djenontin and Meadow (2018). The case studies took place in areas across the world, from the Canadian Arctic to rainforests in Queensland, Australia (Figure 2). They focused on diverse environmental fields, including agriculture, climate adaptation,

conservation and wildlife management, environmental management, and waste management.

Figure 2

Case Study Location and Environmental Field



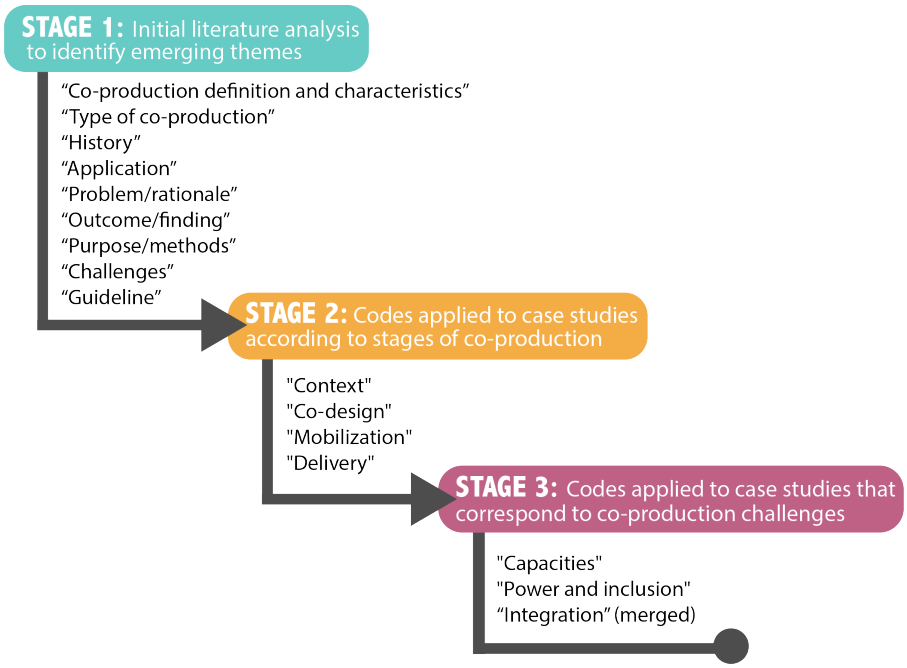
Note. Map visualizes the locations of the case studies with a marker that symbolizes the project's environmental focus.

A rigorous reading and coding of the case studies allowed commonalities to emerge, which helped the overall coding scheme to progressively narrow (See appendix). In a stepwise fashion, the first set of codes corresponded to those used in the initial analysis of technical literature. Upon further reading the case studies, in conjunction with the broader literature, common stages to co-production became evident. The stages, including "context," "co-design," "mobilization," and "delivery," were used to once again code the case studies. This round of coding helped to capture and compare the processes that co-production

practitioners are using. The coded segments were subsequently extracted and synthesized according to overlapping activities and guidelines. Upon analysis of the coded text, additional insights revealed that the practices implemented in each of the stages in the case studies corresponded to mitigating common challenges echoed in the broader literature. I once again found a new coding scheme from these challenges: “capacities,” “power and inclusion,” and “integration.” I reread and coded the case studies according to this new code system. Due to overlap, the integration code was combined with power and inclusion. These new, inductive codes provide the organization for the thesis as they represent the critical junctures between the *whether* and *how* of including communities in co-production. By the end of the analysis, I had over 3,200 coded segments in total. Approximately 1,600 of the coded segments were found in the case studies alone.

Figure 3

Codes applied to co-production literature and case studies



Note. The three primary stages of the coding scheme

"Capacities" was applied to any segment of the text that identified barriers to engaging the socio-political contexts and resources that determine the capacity for co-production work (See appendix). It was also applied to the strategies taken during co-production to prevent, adapt, or resolve the constraints. Capacities related most to the 'context' stage of co-production by including the institutional factors and inputs that either bolstered or impeded the process, such as funding, timing, personal and professional priorities, and skills for facilitation.

"Power and inclusion" was applied to any segment of the article's text that related to power dynamics, both societal and in knowledge, which constrain inclusion and evoke mistrust among the participants. Although

derived from contextual dynamics, this code was most applicable during the process as it was attached to any activity, behavior, or outcome that alluded to an imbalance in power among participants or factors prohibiting their full inclusion. In addition, it was applied to practices and the choices of facilitators that brought awareness to the power dynamics and/or enabled inclusion. For example, a communication strategy tailored towards numerous participants would count as a practice that does not prioritize one stakeholder over another while guaranteeing the transparency of results and thus more integrative participation.

These coded segments were extracted, analyzed, and further organized into subcategories according to inductively derived themes. Within each of these subcategories, I organized the information according to the constraints and opportunities. The constraints draw not only from the case studies but from the wider literature identifying disparities in co-production and collaborative research with diverse participants more generally, and how these might serve to preclude community participation. The opportunity sections trace the practices, activities, tools, and deliberate decisions used in the case studies that might serve as a starting point for practitioners to recognize and overcome the challenges currently limiting inclusion and co-production as a whole.

Table 1
Summary of chosen articles and case studies.

Article	Co-production Approach	Location/Project	Environmental Field	Co-researchers	Case Study Aim
Akpo et al. (2015)	Action Research	Benin	Agricultural systems	University scientists; local nursery holders; extension agents; and community farmers	The study engaged multiple stakeholders of the oil palm seed system in a joint experiment to identify seedling production practices that satisfied all stakeholders interests and needs.
Castellanos et al. (2012)	Rapid Assessment Process	Mexico; Guatemala; Honduras; and Costa Rica	Agricultural systems	University scientists; municipal government officials; nongovernmental organization representatives; hired communication organizations; and community farmers	The study sought to understand drivers of change in the Mesoamerican coffee system and the responses to experienced and perceived vulnerability by farmers, farmer cooperatives, and policy-makers. Researchers aimed to identify the aspects of farmers' decision-making and the ways in which their decisions affect the surrounding landscapes.
Cullen-Unsworth et al. (2012)	Action Research	Queensland, Australia	Conservation and wildlife management	University scientists; international agency representatives; municipal government officials; indigenous administrative officials; indigenous organizations; and aboriginal community residents	The study linked biophysical and cultural indicators appropriate for monitoring and evaluating the Wet Tropics World Heritage Area (WTWHA). Researchers supported adaptive co-management by working with rainforest Aboriginal communities living within the WTWHA to co-produce indicators for current and future reporting processes.
Davidson Hunt and O'Flaherty (2007)	Action Research	Shoal Lake, Ontario, Canada	Environmental management	University scientists; regional indigenous administrative officials; and community residents	The study featured scientists working with elders of the Iskatewizaagegan No. 39 Independent First Nation (IIFN) to better understand and communicate their approaches to resource management to external audiences. Efforts included documenting nontimber forest values and linking the values to resource inventories.

Article	Co-production Approach	Location/Project	Environmental Field	Co-researchers	Case Study Aim
Gutberlet (2015)	Action Research	Sao Paolo, Brazil	Waste management	University scientist; municipal government officials; nongovernmental organizations; project administrators; and recycling cooperatives and community informal recyclers	The study was a seven-year "Participatory Sustainable Waste Management" (PSWM) project that used action-oriented and participatory methodology to increase the safety, effectiveness, and income generation of waste recycling in Brazil.
Kench et al. (2018)	Transdiscipinarity	Hawke's Bay, New Zealand	Climate adaptation	Research institution scientists; university scientists; municipal government officials; local business representatives; environmental consultants; utility operators; and community residents	The study documented a research project titled ‘ Living at the Edge,’ which aimed to strengthen the resilience of coastal communities to coastal hazards. Since the project is still ongoing, the article focuses on the earlier stages of co-production.
Kraaijvanger and Veldkamp (2017)	Action Research	Tigray, Ethiopia	Agricultural systems	University scientists; and community farmers	The study analyzed research strategies of farmer groups engaged in a four-year participatory experiment to test different technologies and interventions to enhance soil fertility and crop productivity.
Moller et al. (2009)	Action Research	Rakiura, New Zealand	Conservation and wildlife management	University scientists; regional indigenous administrative officials; and community residents and land managers	The study documented a 14-year research project with indigenous Rakiura Māori communities to determine the sustainability of sooty shearwater harvests.
Pearce et al. (2009)	Transdiscipinarity	Ulukhaktok, Northwest Territories, Canada	Climate adaptation	University scientists; regional Inuit organizations; and indigenous community residents	The study involved Arctic communities to document their exposure, vulnerability, and adaptive responses to changing socio-ecological surroundings, including physical and socio-economic forces.
		Arctic Bay; and Igloolik, Nunavut, Canada	Climate adaptation	University scientists; regional Inuit organizations; and indigenous community residents	The study worked with Arctic communities to delineate vulnerabilities to climate change and identify areas most suitable for policy aimed at enhancing their adaptive capacity.

Article	Co-production Approach	Location/Project	Environmental Field	Co-researchers	Case Study Aim
Pearce et al. (2009)	Transdiscipinarity	Cape Dorset; Pangnirtung; and Igloolik, Nunavit, Canada	Climate adaptation	University scientists; regional Inuit organizations; and indigenous community residents	The study explored the significance, use, and change of local and regional sea-ice processes according to traditional knowledge with three Inuit communities. Outputs from the project offer a baseline for impact and vulnerability assessments.
Pohl et al. (2010)	Rapid Assessment Process	Makueni District, Kenya	Climate adaptation	University scientists; agro-pastoral households; government officials; and local and regional organization representatives	The study aimed to reduce the vulnerability of agro-pastoral communities to climate and livelihood insecurity by enhancing drought management and interactions between local actors.
		Switzerland	Agricultural systems	University scientists; government officials; and community farmers	The study connected stakeholders involved in soil protection for agriculture to improve responses from detection through to enacting remedial policy.
		Tunari National Park, Bolivia	Environmental management	University scientists; national government officials; and indigenous Quechua communities	The study worked with stakeholders to Tunari National Park in co-producing a management plan that redefines access to the park's resources and more accurately represents the area's indigenous communities and their existing practices.
		Kangchenjunga Conservation Area, Nepal	Conservation and wildlife management	University scientist; government agency officials; non-governmental organizations; and community residents and land managers	The study sought to redesign the conservation policies of the Kangchenjunga Conservation Area Project that previously excluded local communities and their livelihood concerns.

Article	Co-production Approach	Location/Project	Environmental Field	Co-researchers	Case Study Aim
Raymond et al. (2010)	Participatory Integrated Assessment	Peak District National Park; North Pennines; and Galloway, Scotland (Uplands), United Kingdom	Climate adaptation	University scientists; municipal government officials; utility operators; nongovernmental organizations; and community residents and land managers	The study took place at three uplands sites using qualitative and quantitative methods to build decision support tools for monitoring, predicting, and adapting to environmental changes. The knowledge and tools were co-produced with different types of knowledge for climate preparation and response.
		Kahua, Solomon Islands	Environmental management	University scientists; regional governance organization representatives; and community residents	The study aimed to empower local communities to take part in environmental decision-making and land-use, while helping to promote their livelihoods. The project emphasized social learning and facilitating a dialogue between stakeholder groups.
		Victoria, Australia	Environmental management	University scientists; regional government officials; community residents; and park visitors	The project identified and mapped the values and preferences of residents, visitors, and government representatives for tourism planning and development in the Otways region.
Shaffer (2014)	Action Research	Mlingotini; Makurunge; Chekereni; and Rau, Tanzania	Climate adaptation	University scientists; regional organizations; and community residents	The study involved four rural Tanzanian communities to bolster their traditional ecological knowledge, increase their adaptive capacity, and improve stakeholder exchange by monitoring and assessing local ecological indicators. The outputs could feed into projections and forecasts for more relevant climate products.
Wolfe et al. (2007)	Participatory Integrated Assessment	Fort Resolution, Northwest Territories, Canada	Climate adaptation	University scientists; local school employees; local organization representatives; regional indigenous administrative officials; and Dené and Métis community residents	The study sought to document hydroecological conditions of the Slave River Delta and local perceptions of environmental change from the nearby Fort Resolution community, which includes the Dené and Métis indigenous groups. The search was intended to improve stewardship of local resources, as well as the ability of the community to respond to change.

Local Knowledge

The term ‘community’ is often evoked within two contexts: when describing social groupings or networks of people that share common interests (i.e. scientific community); and when referring to geographically localized settings or entities (i.e. village) (Theodori, 2005). Berkes (2004, p. 623) describes communities as “elusive and constantly changing. A community is not a static, isolated group of people. Rather, it is more useful to think of communities as multidimensional, cross-scale, social-political units or networks changing through time.” Many of the communities of focus within participatory environmental resource and management approaches, such as in community-based conservation, are often communities whose livelihoods, institutions, relationships, and experiences are tied to natural resources and the local ecology through social, cultural, and economic links (Adams et al., 2014; Berkes, 2004). These are the forms of community that are primarily referenced within this thesis, whether it be indigenous (Pearce et al., 2009) or nonindigenous (Kraaijvanger et al., 2016), networks of people sharing similar livelihoods (Gutberlet, 2015) or geographically-bound rural areas (Shaffer, 2014). They are local, non-scientific resource-based communities of residents that maintain dynamic local or traditional ecological knowledge (TEK).

Within socio-ecological systems, knowledge (TEK or scientific knowledge), institutions (i.e. rules and norms), and governance (management) constitute the links between the coupled social and

ecological subsystems (Berkes, 2017). These links and their surrounding subsystems are in constant interaction through mutual feedback relationships, where they are adaptively evolving together, or co-produced. The resulting local practices, beliefs, and knowledge of the socio-ecological systems are accumulated and transmitted across generations.

Local knowledge is best understood as a process, “a way of observing, discussing and making sense of new information” and better understanding of the local patterns, signs, and signals from the environment over varied spatial and temporal scales (Adams et al., 2014; Berkes, 2009b, p. 153). The knowledge-building process involves knowledge being formed, validated and adapted to changing environmental conditions, providing a holistic understanding of cycles of resource availability, shifts in climate, and other dynamics of complex systems. Traditional ecological knowledge is defined as the “cumulative body of knowledge and beliefs, handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment” (Berkes et al., 1995, p. 282). This traditional knowledge may or may not be regarded as ‘indigenous,’ where indigenous knowledge is any local knowledge held by people who self-identify as indigenous (Lebel, 2013). More generally, traditional ecological knowledge is a characteristic of communities with historical continuity in resource use practice (Berkes et al., 2000).

The inclusion of local socio-ecological knowledge provides insight into local conditions, ecological patterns, and challenges that scientific knowledge alone could not answer. Traditional ecological knowledge of indigenous communities can be understood as a historical library of knowledge on how to contend and adapt to change in the face of uncertainty and unpredictability that is characteristic of all ecosystems (Berkes et al., 2000). Local knowledge and capacity are constantly changing in response to internal and external processes, thus it is adaptive by nature and maintains a holistic orientation (Berkes et al., 2000; Naess, 2013). This awareness of change is the result of repeated observations over generations using biological and ecological indicators and a deeper understanding of the physical impacts and thresholds of environmental regimes (Lebel, 2013). This contextual understanding of the local environment and challenges renders the knowledge holders as their own forms of experts, whereby the traditional knowledge enables communities to monitor, respond, and manage the processes and functions of the complex system in which they are embedded. For example, Huntington (2011) describes his first experience with traditional knowledge while working as a researcher in an Alaskan village with a local whaling commission; the local whalers were able to map the changes in the sea ice and local ecologies, information that was absent from the scientific literature. In a subsequent project studying the decline of black leather chitons in the lower Kenai Peninsula of Alaska, the collaborative

research and inputs from local experts was indispensable to the project's success (Huntington, 2011; Huntington et al., 2011).

Community-based approaches to resource management and governance are increasingly recognized as relevant and effective in achieving sustainability outcomes (Adams et al., 2014). The communities manifest effective conservation and resource management models (Berkes et al., 1995). Communities that depend on their local natural resources have the institutions in place to manage common resource pools and ensure their sustainability over the long term (Ostrom, 2009). A study by Gutiérrez et al. (2011) found that the most successful fisheries were those co-managed at a local level. The effects were strongly linked to social-ecological dynamics, where participation of local fishers and decentralized institutional arrangements benefited the communities and their economic revenues while minimizing overexploitation. Whereas these outcomes and community-based approaches incentivize ecologists and policymakers to undertake community-engaged research, scientific research and techniques may conversely support community environmental outcomes by supplying valuable information or tools. For example, Shaffer (2014) supplied four rural, Tanzanian communities with environmental equipment and training to monitor, collect, and analyze various ecological data points to make sense of local environmental changes. The activities and resultant data empowered communities to

develop climate adaptation options and strengthened their appreciation of their local climate TEK.

Historically-induced vulnerabilities put indigenous peoples and local communities on the so-called “front lines” of climate change. The unprecedented rate at which socio-ecological systems are changing make it increasingly difficult for communities to interpret, respond, and adapt to new conditions (Crate & Nuttall, 2010). The location of indigenous peoples and local communities are often in economically and politically marginalized areas of fragile ecosystems highly susceptible to environmental degradation and climate shifts. Yet, residents of these communities have arguably contributed the least to greenhouse gas emissions. The implications of rapidly changing environments reverberate through the socio-ecological system, impacting the use, protection, and management of ecosystems, species, and resources, while also affecting the cultural traditions, customs, and economic activities. Climate change exacerbates existing problems, such as poverty, marginalization, and exclusion from discourses and processes of decision-making (Crate & Nuttall, 2010). Thus, climate change threatens a loss of the ecological linchpins of these societies, inducing a loss of identity, a loss culture, a loss of resilience. Decisions about environmental mitigation and adaptation do not occur in a vacuum, rather they are deeply tied to local cultural and socio-economic conditions (Pearce et al., 2009). Management and conservation planning informed by centralized science-

based models of research are often criticized and mistrusted when local land-use goals are not considered and community stakeholders are not included as equal participants (Adams et al., 2014). Researchers have an ethical obligation to interact with the communities at the focus of research, as they are experiencing the conditions being studied and will be affected by the research results (Pearce et al., 2009).

Stakeholder engagement for the co-production of knowledge helps bring to light some of the uncertainties recognized in current research pertaining to a region, while gaining buy-in and support from participants to facilitate the research (Carney et al., 2009). Balazs and Morello-Frosch (2013) describe how community-based participatory research improves the rigor (sound science), relevance (asking the right questions), and reach (dissemination to diverse audiences) of science. These correspond to the requirements, as outlined by Cash et al. (2003), needed to bridge knowledge and action for sustainability. They argue that scientific knowledge is most influential in effecting social change when the information is perceived as credible, salient, and legitimate.

Community-based environmental research engages both local residents and scientists in processes of mutual exchange and learning to better understand environmental variability and change at a local scale. This contrasts with the prevailing global facts generated by scientists by again rendering the local meaning-making contexts relevant for better-informed decision-making (Hulme, 2010). Participatory engagement and

collaboration between environmental scientists and local communities is "key to co-production of knowledge at scales important for livelihood activities, adaptive capacity building, TEK maintenance, and cultural reproduction in a rapidly changing world" (Shaffer, 2014, p. 329). The understanding of knowledge as a process presents the opportunity for researchers to engage communities as co-producers of salient and useful knowledge (Davidson-Hunt & O'Flaherty, 2007).

Co-production Background

Co-production has grown in popularity as an analytical idiom to understand the nested hierarchies in science and governance, as well as a concept to frame the design and execution of sustainability research and action, yet there remains confusion over its precise meaning and application (Miller & Wyborn, 2018). This had led to offshoots of co-production to accomplish specified ends, including a more recent utilitarian turn towards producing climate services to meet the needs of decision-makers. A better understanding of its conceptual origins and current applications is necessary to reinterpret co-production in its full complexity and prevent practitioners from cherry-picking theory for the sake of usability. The theoretical traditions of co-production offer insights into the challenges, such as power dynamics, currently confining the practice of co-production.

The term co-production, in its current conception, was first used by Elinor Ostrom and colleagues in the 1970s within the context of public services (Ostrom & Ostrom, 1978). Ostrom defined co-production as “the process through which inputs used to produce a good or a service are contributed by individuals who are not in the same organization…Co-production implies that citizens can play an active role in producing public goods and services of consequence to them” (1996, p. 1073). The early literature on co-production focused on public and private actors for the co-creation and delivery of public services, such as education, health,

policing, welfare and more (Miller & Wyborn, 2018; Parks et al., 1981; Percy, 1978). Ostrom's work was pivotal in advancing the idea that citizens were not solely the passive recipients of public services by government agencies (Bremer & Meisch, 2017; Ostrom, 1996). Successful public services were the products of engaging citizens as active participants in their production and consumption.

Co-production also appears early in the field of science and technology studies (STS) as an analytical concept to interpret the changing relationships, or co-production, of science, society, and nature (see 'descriptive co-production' below). Sheila Jasonoff is primarily attributed to its introduction within STS, (theoretically) as a constructivist 'idiom' describing the social nature of science, facts, practices, and their authority within layered cognitive, institutional, and political systems (Jasanoff, 2004; Latour, 1987). In this way, co-production is a natural phenomena, as knowledge both constructs society and is an outcome of it (Mach et al., 2020). STS analyses use co-production to better understand how science and governance are enacted together through the production and legitimization of knowledge, as well as the power dynamics entrenched in these relationships (L. van Kerkhoff & Pilbeam, 2017; Wyborn et al., 2019). Co-production provides a theoretical vantage point to understand the emergence of techno-scientific artifacts and framings, and the influence of contexts on science's cultural practices (Jasanoff, 2004; Latour, 1987; Latour & Woolgar, 2013). It sheds light on the social

construction of scientific legitimacy and authority, therefore science is seen as “as much the product of politics and power as of research” (Jasanoff, 2004; Miller & Wyborn, 2018, p. 2). Jasanoff also applied co-production to regulatory settings, where the construction and use of knowledge is embedded in the various arrangements and practices of governance (Jasanoff, 2004; Muñoz-Erickson, 2014).

Co-production also arose within sustainability sciences to challenge traditional research paradigms and call attention to the range of scales that impact processes across socio-ecological systems (Berkes, 2017; Carolan, 2006; Cash et al., 2003). Armitage et al. (2011, p. 996) define co-production as the “collaborative process of bringing a plurality of knowledge sources and types together to address a defined problem and build an integrated or systems-oriented understanding of that problem.” Sustainability science reinterpreted the role of scientists as partners in the negotiation and production of shared knowledge alongside other groups of knowledge holders, such as environmental managers, to jointly address societal challenges (Wyborn et al., 2019). Like scholars of public administration, sustainability science evokes co-production as an intervention meant to transform the practice of science and governance to enhance sustainability.

Co-production has been applied as well to a number of other fields within and outside of environmental research. Other researchers have invoked co-production to describe the collaborative partnerships and co-

learning inherent to the co-management of resources among indigenous communities, local governments, and science (Berkes, 2009a; Kofinas, 2009). To this end, co-production is described not only as a research process; it is understood as a governance strategy as well (Schuttenberg & Guth, 2015). Applied ecology has given rise to adaptive co-management, in which co-production is described as a strategy for successful co-management systems (Berkes, 2009a; Folke et al., 2002). Adaptive co-management features collaboration and learning-by-doing in an ongoing, reflexive process of testing and modifying institutional arrangements and ecological knowledge for decision-making and governance of environmental resources (Armitage et al., 2007, 2009; Plummer & Armitage, 2007). Other areas of environmental research and management have sought to co-produce locally relevant knowledge, including protected areas and biodiversity conservation (Berkes & Davidson-Hunt, 2006; Moller et al., 2009), environmental monitoring (Moller et al., 2004; Shaffer, 2014), agricultural management (Carolan, 2006; Islam et al., 2011; Podestá et al., 2013; Prokopy et al., 2017), and climate change (Boon et al., 2019; Carter et al., 2019; Homsy & Warner, 2013). Global programs, such as Future Earth, have since integrated co-production as a core design element in their sustainability research (Miller & Wyborn, 2018; van der Hel, 2016). This approach to co-production emphasizes its instrumental value for collaboratively building knowledge

for specific policies or problems, which establishes the link between knowledge and action (Dilling & Lemos, 2011; Wyborn, 2015).

Co-production has most recently been adopted by scholars in the climate sciences and adaptation fields (Lemos & Morehouse, 2005; Wamsler, 2017; Ziervogel et al., 2016). More specifically, the procedural, normative theories of co-production (discussed below) have been increasingly applied to the field of climate services, which has steadily grown over the past 15 years (Bremer et al., 2019; Bremer & Meisch, 2017). These studies are primarily concerned with the actionability of science, focusing on iterative processes to improve services, such as climate assessments or tools, that can be used by end users. They reflect the priority to discern local mechanisms and responses to the effects of global climate change (Wyborn et al., 2019). Emphasis is placed on bridging the divide between science production and application to solve pressing climate issues. In the efforts to generate more usable knowledge, emphasis is placed on the inclusion of policymakers and other decision-makers as better able to bridge the usability gap between the supply and demand for climate science. Much of this co-production scholarship highlights the value of co-production in generating usable and actionable knowledge for decision-making. The usability of science refers to its influence in decision and policy-making. For example, climate assessments are tools often co-produced to facilitate decision-makers at the scales best suited to address social concerns (Lemos & Morehouse,

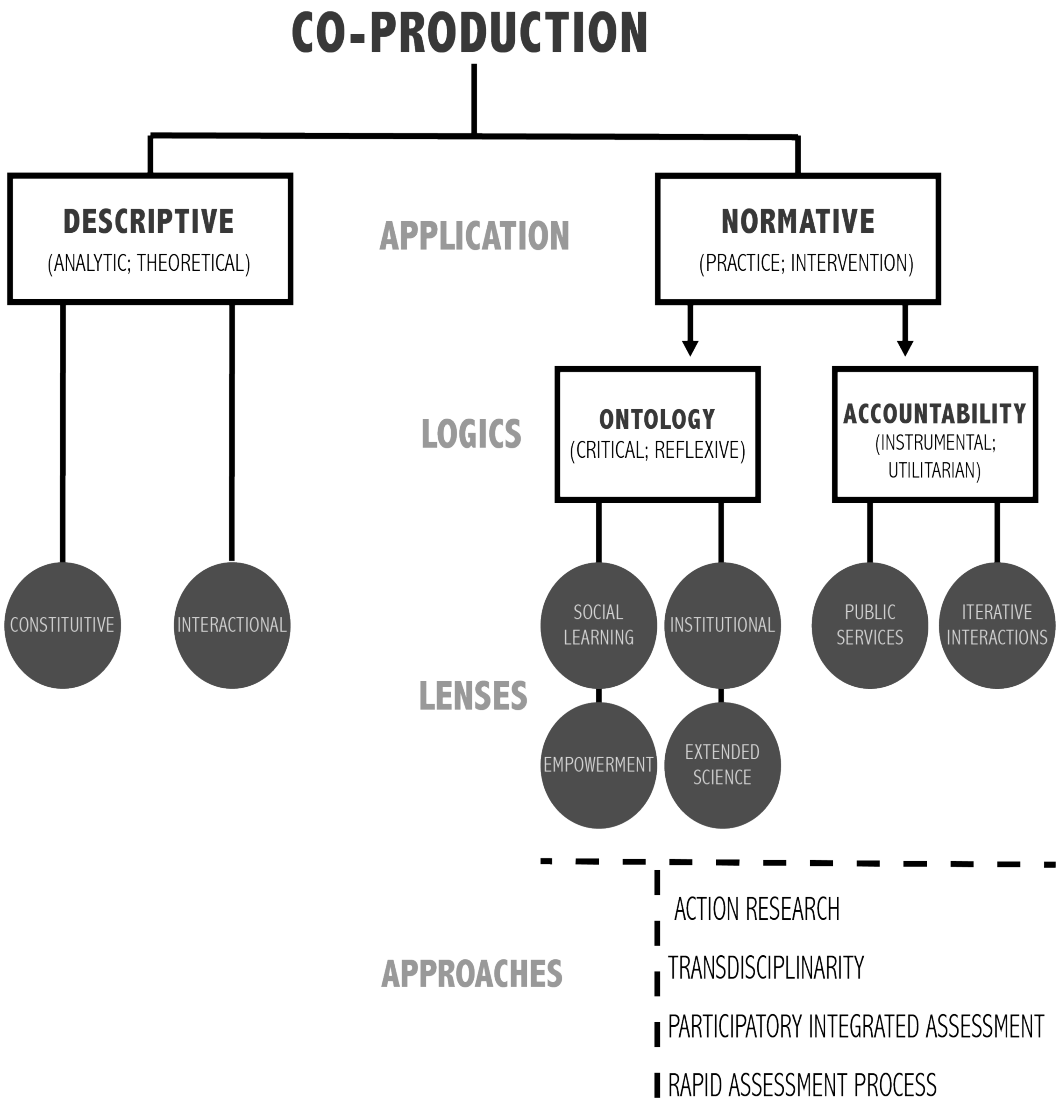
2005). Readily usable knowledge that contributes to policy or solutions to problems is adapted to the scales and contexts as identified by the 'end-users.'

Theoretical Underpinnings

The origins of co-production reflect the current division in its conceptual applications for science and environmental studies. The term 'co-production' has gained prominence within two different contexts: (1) for descriptive, ontological analyses and (2) normative, procedural applications (Bremer & Meisch, 2017; Lövbrand, 2011; Prokopy et al., 2017). Descriptive co-production takes a constructivist approach to describing and analyzing the changing relationships between science, society, and nature. Normative co-production is a deliberative, procedural participatory mechanism for engaging nonscientists. Scholars of the normative type focus on the best practices, implementation, and evaluation of co-production processes, in other words how practitioners *should* carry out its design and implementation (Bremer & Meisch, 2017). These two applications, and the corresponding lenses, logics, and approaches (Figure 4), muddle the conception of co-production, pushing many to one side or the other and perpetuating the assumption that little overlap exists (Wyborn et al., 2019). Yet a juxtaposition of these two modalities reveals how scholars on the descriptive side investigate and theorize about the very dynamics that pose challenges to co-production in practice.

Figure 4

The Theoretical and Practical Applications of Co-Production



Note. Conceptual diagram depicting the applications, logics (Lövbrand, 2011), lenses (Bremer & Meisch, 2017), and approaches (Meadow et al., 2015) to co-production for environmental research. Source: Author.

Descriptive

One primary application of 'co-production' is as a descriptive, constructivist concept that highlights the existing ways in which science and governance are continually reproduced together at various scales

inscribed in social, cultural, and political contexts (L. E. van Kerkhoff & Lebel, 2015; Wyborn et al., 2019). This ontological perspective argues that science and knowledge are inseparable from society and governance, therefore they are co-produced together, “each underwriting the other’s existence” (Jasanoff, 2004, p. 17). In this way, co-production is an analytical approach used to identify and examine problems related to the evolving interactions between science, society, and nature, particularly the social orders and power dynamics that commonly arise from these relationships (Bremer & Meisch, 2017; Lemos et al., 2018; Lövbrand, 2011).

Since governance and science are constructed and carried out together, scholars of descriptive co-production strive to ascertain the power dynamics subsumed in these relationships (Wyborn et al., 2019). Science and technology are understood as social practices designed to establish structure and authority in a society, ergo tools of power (Jasanoff, 2004). Knowledge and decision-making processes should be examined as dynamic and inextricably connected, spanning socio-political scales (Hulme, 2010; Jasanoff, 2010; L. E. van Kerkhoff & Lebel, 2015). Current discourses of environmental change have been abstracted to the global scale, which have led to the globalization of producing knowledge, decisions, and scientific ‘facts.’ Such narratives have implications on the designs and types of solutions, and methods for getting them, aimed at ameliorating environmental problems. This global framing and

universalized science is alienated from the diversity and challenges seen at local levels of meaning-making contexts (Hulme, 2010). Descriptive co-production brings to light the “important relationships between science and governance that exist at multiple scales and are embedded in social, cultural, and political contexts” (L. E. van Kerkhoff & Lebel, 2015, p. 2). This literature critically delves into the sociopolitical and institutional settings, framings, and processes that are imbued in knowledge production and the subsequent societal outcomes.

Jasanoff (2004) identifies two strands of descriptive co-production theory, constitutive and interactional. The constitutive lens deals with the ways in which science evolves with institutions and wider social, political, and economic systems that are responding to our perceptions of nature and society (Bremer & Meisch, 2017). In other words, this lens addresses the cognitive interface between nature and society, where our representations of the natural world frame how we choose to live and govern it. This descriptive lens seeks to account for how “people perceive elements of nature and society, and how they go about relegating part of their experience and observation to a reality that is seen as immutable, set apart from politics and culture” (Jasanoff, 2004, p. 19). These co-productionist narratives are concerned with how certain states of knowledge emerge and are either sustained or abandoned. Those systems of thought that are held onto take root, stabilize, and gain power in shaping perceptions of identity and place in the world. Knowledge

becomes a means by which stability is developed and maintained in the face of new facts and systems of thought. The constitutive approach is a useful analytical tool for examining scientific practices and their subsequent impacts on social and natural orders, and identifying the (mis)use of science in decision-making (Bremer & Meisch, 2017).

The interactional approach to co-production is not so much concerned with how people 'know,' but rather what happens when existing epistemologies are at odds with one another (Jasanoff, 2004). Boundary conflicts arise when the limits of knowledge domains are called into question, such as when attempting to distinguish science and society, facts and values, or knowledge and power (Bremer & Meisch, 2017). This lens seeks to understand how humans organize and reorganize their ideas about reality in response to this clash in epistemologies. Jasanoff (2004, p. 19) contends that the interactional approach endeavors to "elucidate the myriad mutual accommodations between social and scientific practices that occur within existing socio-technical dispensations during times of conflict and change." Whereas the constitutive lens looks at evolving dynamics in response to new systems of thought, the interactional lens examines the knowledge conflicts resulting from established delineations between realms thought of as separate, such as society and science. The interactional mode of co-production is often deployed when challenging the distinctions between science and society and the advantaged position of scientific expertise and global

environmental knowledge, in contrast to local socio-ecological knowledge and place-based understandings (Bremer & Meisch, 2017; Carrozza, 2015).

Whether deliberately taking a co-production participatory approach to research or not, co-production is still occurring according to STS scholars. We are constantly in processes of generating new knowledge and reshaping our existing views to accommodate them. Access to knowledge, science, technology, and governance are tightly bound with the resources, institutions, and power dynamics that permeate society.

Normative

In contrast to the descriptive perspective, the normative perspective of co-production takes a procedural turn by including scientists and non-scientists alike in concerted co-production of a shared body of knowledge. Thus, co-production takes the form of an intervention. The normative approach to co-production involves new ways of engaging science and society through deliberate processes, practices, and tools to actively manage and enhance the relationships between co-researchers (Bremer & Meisch, 2017; Lemos et al., 2018; L. E. van Kerkhoff & Lebel, 2015). This conception of co-production extends beyond solely interpreting the ways in which knowledge systems create order in the world; it takes a more active and prescriptive stance to deliberately engage non-scientists in developing and using knowledge (Lövbrand, 2011). This practice of co-

production transforms the conventional application of science and governance to develop new knowledge (Wyborn et al., 2019).

In practice, co-production is associated with a plurality of terms, including “joint knowledge production” (Hegger et al., 2012), “co-creation” (Kench et al., 2018; Voorberg et al., 2014), “co-learning,” “knowledge exchange” (N. Young et al., 2016), and “interdisciplinary community collaboration (ICC)” (Bayne-Smith et al., 2008). Practitioners engage in the co-production process for a variety of outcomes, making its praxis convoluted. For example, predominant applications of co-production practice prioritize usable knowledge (Meadow et al., 2015), but another practitioner might use co-production as a means of community empowerment (Gutberlet, 2015). A review by Bremer and Meisch (2017) differentiate six different objectives, or ‘lenses,’ for co-production, which include a) producing usable science through iterative participation, b) extending science with the inclusion of nonscientist stakeholders, c) producing public goods and services, d) enhancing the capacity for adaptation for institutional resilience, e) fostering social learning about climate and environmental issues that relevant actors find useful, and f) empowering systems of traditional ecological knowledge. Although their work focuses on the context of climate research, the map of six normative co-production lenses that they uncover are applicable to a broader context of environmental research and management.

Underlying motives for co-production can be delineated into two ‘logics’ for scholars to engage public participation in co-producing science together (Lövbrand, 2011, p. 227). The ‘logic of ontology’ emphasizes critical, reflexive efforts to stimulate ontological change in opposition to dominant scientific enterprises by highlighting the inclusion of multiple perspectives and the collective capacity to shape society, similar to the objectives espoused by descriptive STS scholarship. Normative co-production, according to this rationale, creates space for more open-ended and inclusive collaborations that reflexively examine new questions and perceptions that shape society but were previously excluded. The second “logic of accountability” underpinning the practice of normative co-production pertains to transforming research to prioritize its application in addressing societal needs. Co-production according to this rationale takes on an instrumental and utilitarian function, which is most closely associated with more problem-focused sciences (L. van Kerkhoff & Pilbeam, 2017). This logic does not emphasize the need to “open up and transform existing ways of thinking” so much as it is “concerned with adjusting research portfolios to the plurality of knowledge needs in society” (Lövbrand, 2011, p. 227). Van Kerkhoff and Pilbeam (2017) refer to these two underlying reasons driving co-production as the critical/reflexive perspective and the instrumental/utilitarian perspective. These two logics for the practice of normative co-production shape the types of

stakeholders engaged, as well as the design and outcomes of the process.

Lövbrand (2011) has drawn attention to the underlying tensions that exist between these two perspectives. The ontological logic of co-production opens the process to the multiple ways of knowing and experiencing nature, thus multiple types of knowledge holders from society are included in the democratization of science (Lövbrand, 2011; L. van Kerkhoff & Pilbeam, 2017). Co-production, according to this logic, facilitates empowerment and deeper insight into the social and political context, yet it requires humility for reflexivity and receptiveness to the plurality of ontological assumptions that might exist. In contrast, the logic of accountability, or the instrumental and utilitarian perspective, affords promising possibilities for action and influence, but at the cost of using more traditional approaches to engagement.

More recent scholarship on normative co-production has further deepened the division between the two. Climate research has predominantly emphasized the utilitarian application of co-production through efforts to tailor the process towards producing more usable climate information, such as climate services (Bremer & Meisch, 2017). With this focus on the actionability of knowledge products, normative co-production involves iterative interactions between science producers and users to respond to each other's needs, motivations, and limitations (Prokopy et al., 2017). Thus, the process is often modified according to

the institutional constraints regarding what can be produced and how it can be used in decision-making. More generally, this conceptualization of normative co-production is concerned with bridging the supply and demand for environmental science spanning a ‘usability gap’ (Bremer & Meisch, 2017). Instead of redefining new modes of science and immersing nonscientists into the process, practitioners focus on regularly consulting nonscientists for better customizing research to the existing decision-making context (Bremer et al., 2019; Dilling & Lemos, 2011). This lens of co-production emphasizes success as being measured by the usefulness and actionability of the climate information and services within decision-making.

The division between the normative and descriptive applications of the co-production concept are reflected in the logics underpinning its practice. Thus, practitioners have been drawn to one side or the other, but the gap between the two lenses can be overinflated (Miller & Wyborn, 2018; Wyborn et al., 2019). For example, Latour (1987) argues that production of scientific knowledge is part of a larger social process that creates both the product of science and its utility. He highlights the discrepancy between principle and practice, where the universality of scientific facts or other products might be true in principle, but in practice are applicable only within the controlled conditions in which they were made. He describes the example of a telephone that in principle can call anyone in the world, but in practice it would be difficult, if not impossible,

to call someone living in a remote location without access to a telephone. The outcomes, or results and their utility, of co-production, like any scientific endeavor, are contingent on the social, political, and physical networks in which they are embedded. Thus, understanding the socio-political context surrounding normative co-production, much like the goals of its descriptive counterpart, has the potential to improve its practice and subsequent usability. The descriptive insights underline the complexity and political nature of process, all of which can be better reflected in its design. Better-informed co-production procedures should capture the knowledge processes and capacities within the nested contexts of wider institutions that will ultimately influence the outcomes.

In many ways, a well-planned process contributes to bridging the two applications of co-production. To better shed light on the barriers and corrective strategies for community inclusion in the deliberate practice of co-production, a preliminary exploration of its praxis is warranted. Understanding the variety of applications and lenses of co-production is the first critical step in delineating the methodological approaches, then the procedural stages of the process, to finally the underlying principles influencing the way knowledge is co-produced.

Praxis of Co-production

While co-production promises more effective knowledge processes and outcomes, many continue to grapple with the complexities of its implementation. It is important to understand the scope of approaches,

stages, and design principles that shape the process before more nuanced constraints and opportunities can be distinguished. Although the following section is a summation of the technical literature, each of the case studies employ a co-production approach, undergo the stages, and attempt to optimize the principles and conditions for bringing their jointly-determined outcomes to fruition. Each section synthesizes the normative literature with the aim of providing conceptual and practical clarity preceding the results of the analysis. The first section describes four research approaches that fall within the purview of co-production. The next section summarizes the procedural stages commonly reported within co-production. The final section is a synthesis of the principles most prevalent across normative papers defining co-productive tenets and conditions of success (Beier et al., 2017; Dilling & Lemos, 2011; Frantzeskaki & Kabisch, 2016; Hegger et al., 2012; Hegger & Dieperink, 2014; Miller & Wyborn, 2018; Polk, 2015; Reed et al., 2014; Vincent et al., 2018).

As an aside, the underlying goal for co-production praxis is some degree of transformation to enact change, whether that be in the very act of including citizens in research processes, empowering marginalized groups, or generating usable science enabling action. There seems to be a divergence within the co-production literature, with those more concerned with the knowledge *outcomes*, and those that focus on the *process* of collaboration. The most common outcome prioritized across

environmental studies (namely climate sciences) is useable, actionable knowledge, whereby the knowledge "users" are engaged in collaboration to establish a feedback loop between knowledge-making and decision-making (Bremer & Meisch, 2017; Dilling & Lemos, 2011; Mach et al., 2020; Prokopy et al., 2017). In contrast, those underscoring the process itself see engagement as an intervention reshaping the relationships and interactions between researchers and societies (Mach et al., 2020). This division largely reflects the two logics for co-production, thus how the logics guide the process becomes apparent in the subsequent sections. For example, the approaches designed for a specific outcome, such as a rapid assessment process, place much less emphasis on a committed, collegial process (hence 'rapid').

Approaches

If co-production is the process of collaboration for a specified goal, then participatory research approaches are the means by which to accomplish the principles of co-production. Some of the approaches that have been identified include place-based learning communities (Davidson-Hunt and O'Flaherty, 2007), multiple evidence base (MEB) approach (Tengö et al., 2014), Joint learning (Cullen-Unsworth et al., 2012), participatory integrated assessment (PIA) (Meadow et al., 2015), participatory experimentation (Kraaijvanger et al., 2016; Akpo et al., 2015), boundary work (Nel et al., 2015), and participatory modeling (Podesta et al., 2013). Meadow et al. (2015) explore four general research approaches

to knowledge co-production, including action research (AR), transdisciplinarity, participatory integrated assessment (PIA), rapid assessment process (RAP). These are broad, popular approaches that encompass some of the more specific collaborative methodologies that are less widely theorized. While each research approach features collaborative or collegial types of participatory engagement, they arguably fall along a spectrum of engagement with nonresearcher participants.

Action research is a strategy that emphasizes a network of stakeholders collectively identifying, analyzing, and solving a problem (Greenwood & Levin, 2007). AR promotes democratized relationships, co-producing knowledge about a problem, and culminates in taking action to solve said problem. Due to its politically-charged nature and goal of effecting social change, AR can be considered the most transformative of the research approaches. It is the most disparate to conventional research practices as it redefines the role of researchers to facilitators and tests the boundaries of objectivity. The collegial and transformative scope of AR makes it align most with the ideals of co-production.

Transdisciplinarity is another collegial research approach to co-production, which seeks to collaboratively frame and solve complex societal problems through the sharing of knowledge across scientific fields and among various stakeholders (Lang et al., 2012). Meadow et al. (2015, p. 185) distinguishes transciplinarity from AR in that it “brings the various participants together to accomplish specific tasks, while AR allows for a

more immersive experience in which researchers interact with stakeholders within the stakeholders' social context, which may allow researchers to develop a deeper understanding of stakeholder needs and knowledge systems."

Rapid Assessment Process, or RAP, is an iterative research approach that aims to capture the perspectives of local participants, including aspects they find most important and the terms and knowledge systems integral to knowing about the issues. Multidisciplinary teams work to triangulate data through iterative collaboration with stakeholder communities via observation, interviews, surveys, and other social science methodologies. RAP requires a much less intense form of participation, therefore less time and fewer resources are needed in comparison to AR and transdisciplinary research. The resulting knowledge is usable because it better encapsulates the local issues, institutional dynamics, and decision-making context. Participatory integrated assessment, or PIA, is a research approach to co-production that aims to generate decision-support tools, such as models and scenario planning, in partnership with non-researcher stakeholder groups. RAP and PIA are less inclusive than AR and transdisciplinarity, and can be designed as a purely consultative mode of engagement.

Stages

The process of co-production is generally organized into stages encompassing the initial conception of the project to the final application of

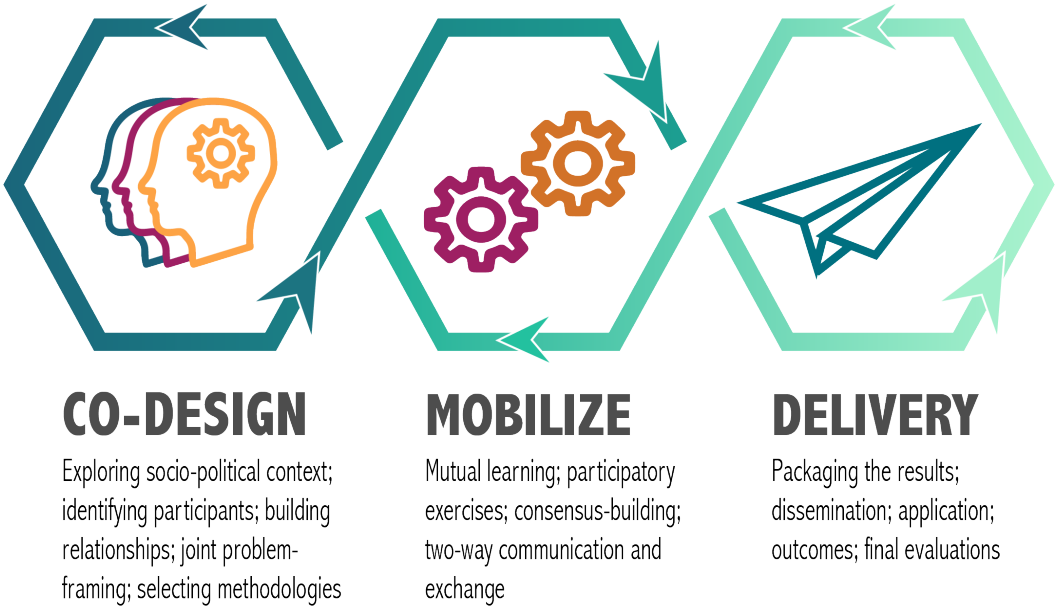
the results and the assessment of the outcomes. Scholars stress the importance of the flexibility, iterativity, and reflexivity of the process, allowing for continued dialogue and the overlap and revisitation of stages (Lemos & Morehouse, 2005; Meadow et al., 2015). Mauser et al. (2013) elaborates on the three steps that comprise the co-production process for the Future Earth initiative, including co-design, co-production, and co-dissemination. Djenontin and Meadow (2018) synthesized elements of nine environmental case studies into a logic model framework of steps, featuring context, inputs, process (activities and outputs), and outcome-impacts. Polk (2015) evaluates a co-production framework developed by Mistra Urban Futures, a transdisciplinary urban development center, which is organized by three research phases: formulate, generate, and evaluate. Cornell et al. (2013) identify three main stages: joint problem framing, knowledge integration, and experimentation. Similarly, Puente-Rodríguez et al. (2016) organize their research project dealing with environmental management systems in port communities according to three phases: initiation, knowledge mobilization, and evaluation and communication.

Co-production can be synthesized into key components of the process: co-design, mobilization, and delivery (Figure 5). The process is embedded within a broader socio-ecological context of stakeholder groups, communities and management systems, social institutions, and world views (Berkes et al., 2000; Wyborn et al., 2019). This context determines the inputs to the process, such as the types of knowledge to

be included, resources, and experience. The co-design phase entails building the research team and designing the project. This stage is dedicated to jointly framing the problems and research questions that have value to each stakeholder, developing a research agenda and protocols, and determining salient methods and forms of dissemination. Upon initiating the project, practitioners must identify the contextual factors, such as resources, cultural differences, institutional demands, and other forces that may serve to advance or impede the process. In the mobilization stage, knowledge is galvanized together for mutual learning through various participatory methodologies. This part of the process is the actual carrying out of the research, where stakeholders engage in learning activities and consensus-building to produce the knowledge and/or products to satisfy the research objectives. The delivery stage encompasses the dissemination, evaluation, and application of the co-produced results. This part of the process is primarily concerned with making the outputs accessible to all the stakeholders. The inputs and outputs often operate along a continuum of feedback loops in which the outputs serve as inputs for continued learning. The process is nonlinear and the boundaries between stages are often blurred, where practitioners may need to revisit previous stages or multiple stages may be occurring at once.

Figure 5

Three primary stages of co-production



Note. Three primary stages of co-production

Principles of co-production

The co-production literature identifies fundamental principles that must be present in the design of the co-production process. Although these are not comprehensive, I distilled the principles most commonly attributed to successful outcomes across co-production projects. These include: (1) collaboration (2) inclusiveness; (3) openness and iterativity; (4) flexibility; (5) legitimacy, credibility, and salience; (6) trust. Regardless of the co-production lens or approach, these principles conditions were stressed to varying degrees by nearly every article providing a normative framework for co-production. These principles each help in overcoming

the challenges, thus subsequent sections on ‘opportunities’ are concerned with *how* to ensure the conditions are met.

A central tenet of co-production is maintaining a collaborative process that fully integrates scientists and non-scientists alike as equal participants. The degree to which stakeholders participate occurs along a continuum of different engagement modes that reflect the character of interactions between scientists and decision makers (Balazs & Morello-Frosch, 2013; Biggs, 1989; Harris & Lyon, 2014; Meadow et al., 2015). The participation continuum moves from the minimal involvement of communities as study participants by traditional scientific endeavors to engagement as equal research partners. Along the continuum, four overarching modes of engagement exist that shape the relationships between researchers and other participants: (1) contractual (unidirectional exchange of information); (2) consultative (selective, two-way exchanges of information); (3) collaborative (influence over the outcome); and (4) collegial (empowerment for equal partnership and authority) (Biggs, 1989). The long-term, reciprocal relationships and stakeholder involvement required for co-production necessitate collaborative and collegial modes of engagement (Meadow et al., 2015). Collaboration builds upon the inclusion of different actors, needs, and knowledge systems, which is another underlying principle necessary for co-production (Vincent et al., 2018). Inclusionary practices recognize the value of the diversity of expert knowledge for a more creative and holistic process and output

(Frantzeskaki & Kabisch, 2016). In the process of exchanging knowledge and learning, co-production necessitates openness and iterativity to enable sharing (Frantzeskaki & Kabisch, 2016; Lemos & Morehouse, 2005).

The highly interactive nature of co-production means sustaining interaction and ongoing flows of knowledge among participants. Lemos and Morehouse (2005) attribute an iterative process as a key mechanism to producing usable knowledge with a perceived high value. The regular interactions from the onset of the project and defining the problem, all the way to analyzing the results and creating usable information generates a positive feedback loop, or iterativity, of information exchange (Kirchhoff et al., 2013; Kruk et al., 2017; Lemos & Morehouse, 2005).

Flexibility among the participants and institutions is necessary in taking a process-based approach where the path trajectory is uncertain and the stakeholder needs diverse (Lemos & Morehouse, 2005; Vincent et al., 2018). Research agendas may change as the needs of stakeholders evolve throughout the process, which necessitates more flexible resources, time frames, and budgets that shape the relationships between researchers and other participants (Dilling & Lemos, 2011; Frantzeskaki & Kabisch, 2016).

In the efforts to link knowledge to action, the information must be perceived as credible, legitimate, and salient by all stakeholders (Biggs, 1989; Frantzeskaki & Kabisch, 2016; Lemos & Morehouse, 2005; Vincent

et al., 2018). Credibility is equated to scientific rigor and sufficient technical expertise, whereas legitimacy refers to fairness, respectfulness, and unbiasedness of knowledge production, and salience reflects the relevance of the produced knowledge. Finally, the relationship-building central to co-production depends on trust among the diverse participants to initiate the two-way dialogue (Reed et al., 2014; Vincent et al., 2018).

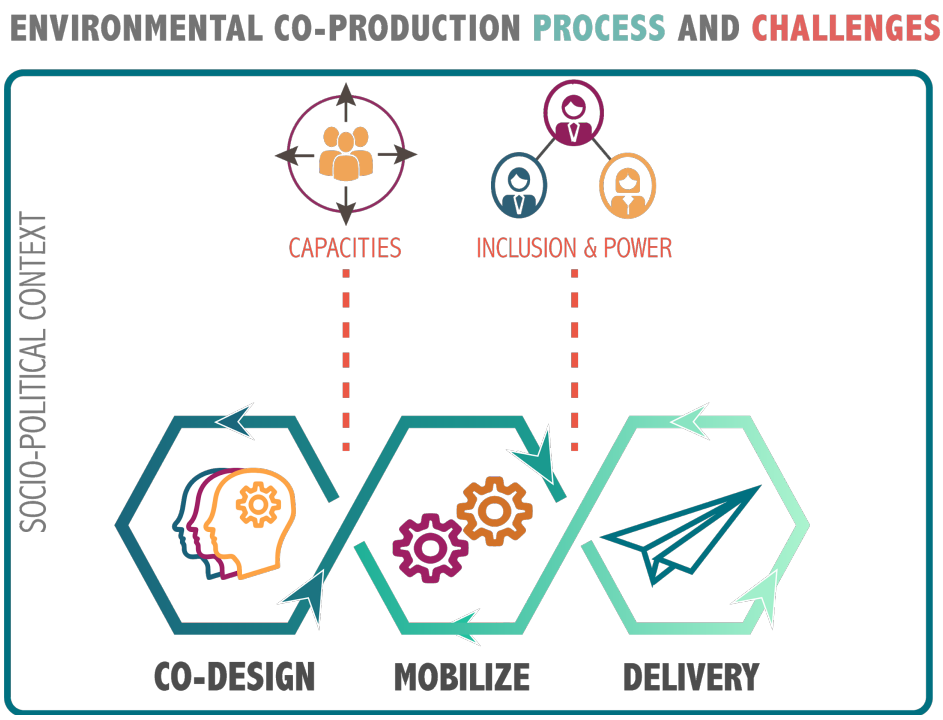
Results

The multitude of challenges to descriptive and normative co-production can be generalized into two critical barriers: institutional capacities and power and inclusion. Institutional capacities refer to the barriers to engaging the sociocultural contexts and resources that determine the capacity for co-production work. Power and inclusion refer to the power dynamics, both societal and in knowledge, that constrain inclusion and evoke mistrust among the participants. These barriers are present throughout the stages of co-production, posing recurrent challenges that must be overcome by all participants equally (Figure 6). Conversely, the barriers also offer windows for reconnecting the normative and descriptive lenses of co-production, especially with the inclusion of local communities.

The following sections examine each of the co-production barriers, organized first by the constraints they pose and then the opportunities they present. The constraints document the obstacles to including and working with communities, whereas the opportunities illustrate the practical methodologies and guidelines drawn from the local case studies to bring awareness to the challenges and begin overcoming them. A majority of the examples are derived from the sample case studies, but on occasion integrate examples from the broader literature to complement insights.

Figure 6

The process and challenges of co-production



Note. Co-production process stages reimagined within a socio-political context with challenges found throughout its application.

Institutional Capacities

Like a knowledge system, knowledge co-production takes place within a broader socio-ecological context of world views, social institutions, and management systems. Berkes et al. (2000) describes this hierarchy of social mechanisms within the perspective of traditional ecological knowledge, yet co-production is subject to the very same social dynamics and institutions. From an environmental perspective, institutions constitute the formal and informal rules and norms that shape environment-society interactions, such as laws, property rights, and management taboos (Brown, 2003; Robbins, 2007). They can be produced by political

mandate, or they can evolve over time through experience, such as traditions (Robbins, 2007). In addition, institutions can consist of both public and private organizational entities, such as a state or a research group that funds environmental research. Institutions include the channels through which societies can act on their respective knowledge (Berkes et al., 2000). Institutional capacities are needed to both carry out the process and achieve immediate and long-term outcomes.

Wyborn (2015) and Van Kerkhoff and Lebel (2015) refer to the socio-political and institutional dimensions surrounding co-production work as “coproductive capacities,” which are the social, normative, material, and cognitive factors that shape the connection between knowledge and action. Facilitation of co-production depends on the capacities to access, produce, exchange, and interpret different knowledges to bring about social change. Shuttenberg and Guth (2015) delineate three sources of co-productive capacity: existing individual and organizational capacities; broader socio-ecological system encompassing biophysical, social, cultural, and institutional factors; and the co-production process itself. It is imperative to understand and engage with the various institutions that comprise the socio-economic context and subsequent capacities in which efficient and effective co-production can operate. A challenge for co-production involves developing the institutional capacity to accommodate diverse stakeholder interests and values while staying flexible and adaptable in the iterative process.

In the rest of this section, the discussion is organized around issues of socio-political dynamics, space, time and funding, and facilitation and their relevance in terms of constraints and opportunities for building institutional capacity.

Socio-political Constraints

An understanding of the institutional structures and needs of stakeholders is paramount to the evolution of knowledge co-production (Campbell et al., 2016). This includes the professional demands of researchers and the political pressures and daily realities of other participants, such as environmental managers, decision-makers, and community members. The diversity of participants in the co-production process brings a range of expectations, motivations, and incentive systems (Scholz & Steiner, 2015). As projects evolve, different incentives and expectations regarding institutional outputs (policy vs. publication vs. outreach), will only become more apparent and risk turning into conflict or hindering the outcomes post-process (Podestá et al., 2013). An example of disparate expectations includes the demand for publishable papers in contrast to building user-friendly tools for enhanced resilience to environmental change (Podestá et al., 2013). In order to generate relevant knowledge and subsequent outcomes for participants, it is necessary to explore the multi-layer institutional contexts in which co-production is embedded.

The success of co-production depends on the capacity of researchers and practitioners to be active participants and engage meaningfully throughout the process (Brouwer et al., 2018). Identifying and then carrying out the priorities and interests of stakeholders in research is far from straightforward. The dynamic goals of community participants for involvement might be to protect the intrinsic value and stewardship of nature (Adams et al., 2014), or to protect their traditions and ability to utilize local resources (Moller et al., 2009). Many of the outcomes of community inclusion in environmental research and management are intangible, including science and community partnerships, new representations of nature and society (Raymond et al., 2017), empowerment (Gutberlet, 2015), social networks and more. This can pose challenges to scientists used to working with more predictable quantitative research methods and data.

Priorities change over time both within the communities and in the surrounding socio-political context, which can have implications for involvement as well as the fit and usefulness of the results and thus outcomes. For example, the project at Fort Resolution along the Slave River Delta in the Northwest Territories prioritized assessing residents' vulnerability and building adaptive capacity to environmental variability, such as flooding (Wolfe et al., 2007). The project aimed to capture northern community priorities and enhance their capacity and involvement in collaborative research. However, various institutional variables posed a

burden for community involvement and enthusiasm, as the pace and politics of the area could be intense and the residents had different interests, pressures, and activities at any given time (Wolfe et al., 2007). Individuals would regularly leave and return to the area due to seasonal employment opportunities, extended stays with family, and trips to land, which made relationship-building and continuity in research engagement difficult.

Co-production occurs within a nested space of complex institutional structures that span spatial and temporal scales. Co-production is often discussed as possessing the capacity to address global environmental change (Cornell et al., 2013; Mauser et al., 2013). The inflation of large-scale institutions and arrangements simultaneously downplays the smaller scales that may be better able to capture the complex interactions and concerns about the natural and social capital of interest (Ostrom, 1998). In working with Mesoamerican coffee farmers, Castellanos et al. (2012) failed to account for the changing priorities of public officials, as well as aligning their recommendations to the scales at which the public officials could take action. As a result, although the work proved useful in building social networks and knowledge exchange among local farmers, the authors report a lack of interest and exclusion of their final reports in the regional decision-making process. The researchers realized the difficulties in mapping the stressors and decision-making contexts of farmers whose daily operations contend with issues outside the domain of the original

research program. Although their objective to “enhance awareness of the institutional opportunities and constraints in the adaptation process” for farmers would be valuable information to policymakers, their lack of attention to the evolving decision-making environment was the decisive factor that prevented their original project goals from being realized. It is thus essential to consider the complexity of scales at which the governing systems operate in order to adequately contend with the complexity of the larger socio-ecological system (Armitage et al., 2009; Ostrom, 1998).

Some institutional structures are not designed to readily integrate co-production projects into their organizations or institutional cultures (Polk, 2015). Co-production calls for radically transforming decision-making by offering a deliberative inclusionary process for decentralizing power (Brown, 2003), which can be disconcerting and not easily integrated into siloed organizations or institutional cultures (Muñoz-Erickson & Cutts, 2016; Polk, 2015; Shaffer, 2014). Hence, the possibility of sustainable outcomes hinge on the ability of the knowledge and co-production arrangements to either be embedded within existing knowledge and political engagements or new, transformative institutions co-produced in the process (Miller & Wyborn, 2018). By failing to address the political and social contexts, and thus co-production capacity, of complex issues, such as resource management, practitioners are also dismissing how the results will reconcile with more formal decision-making regimes.

Knowledge stereotypes and assumptions about who produces and uses knowledge can prevent co-producing a knowledge system that adequately reflects the local context (Muñoz-Erickson et al., 2017). By failing to understand the existing knowledge flows and blockages, co-production risks further augmenting them. For example, in the Slave River Delta, Wolfe et al. (2007) pointed out how information that flows to the community environmental working committee would not necessarily make its way to other stakeholder groups due to revolving organization membership. Understanding the epistemic context of the knowledge system will highlight pathways and barriers to the uptake of co-produced knowledge. The drought management project in Kenya was launched following the lack of success in implementing sustainable drought management and food security initiatives (Pohl et al., 2010). Scientists found that farmers largely ignored scientific recommendations regarding agro-pastoral practices, even when seasonal forecasts were broadcast over the radio.

Socio-political Opportunities

Early engagement with stakeholders offers the opportunity to diagnose the Institutional factors that shape the local capacity for participation and application of their co-produced results. All but two papers reviewed undertook the formative step of identifying the socio-political system parameters of existing information flows and the variables, like shared values, influencing the generation, acceptance, and adoption

of new information. The two that failed to do so acknowledged this misstep as a flaw in their process (Castellanos et al., 2012; Raymond et al., 2010). In the case studies that did so, these exploratory assessments were initiated at the start of the project, and elaborated upon throughout their duration. Early engagements with all of the stakeholders is essential to identify various barriers and how to overcome them, existing technologies in use, social systems affecting current practices, and more. This can be accomplished through introductory field visits (Akpo et al., 2015; Pearce et al., 2009), community meetings (Wolfe et al., 2007), interviews and surveys (Moller et al., 2009), and workshops (Kraaijvanger & Veldkamp, 2017). During initial workshop sessions with local farmers, Kraaijvanger and Veldkamp (2017) uncovered the constraints, context, and opportunities for the ensuing participatory experiment with rural farmers in Tigray, Ethiopia. Outcomes of the introductory workshop provided input for subsequent workshops.

One method for uncovering the socio-ecological context of an area is to create an activity where participants draw what they know about the surrounding system, or conceptual mapping. Catellanos (2012) asked coffee farmers to draw diagrams that illustrate their relationship to their own coffee commodity chain, as they understood it. The researchers found a significant discrepancy in knowledge between independent farmers and those that were members of local cooperatives. Farmers that were not members of farming cooperatives were often only able to identify

the intermediary buyer of their coffee, whereas farmers in cooperatives were able to illustrate the entire commodity chain, including the names of buyers and distributors. Similarly, Gutberlet (2015) and Pearce et al. (2009) utilized conceptual mapping as a methodology to understand the local context and elicit the community's tacit understanding of such.

Early relationship building and personal interactions offer the opportunity to reveal additional institutional dynamics influencing the socio-ecological system in which the community and the co-production project rest. For example, Shaffer (2014) identifies religious beliefs, spaces, and composition of the residents as both a means and limitation of knowledge flows within the rural Tanzanian communities taking part in the environmental monitoring project. Conversations with community members shed light on further variables shaping their need, diffusion, and use of scientific climate information. Such variables included aspirations for education and modernity as a result of a former president that promoted government literacy programs. Similarly, the researcher in the Ulukhaktok arctic project (Pearce et al., 2009), during a consultation visit, began establishing partnerships with local collaborators while learning about the community dynamics and culture. During the research design scientists negotiated fieldwork trips to correspond with participant availability, including their own schedule and those of the community members. Fieldwork was scheduled between May and September, which was not ideal due to warmer conditions and the fact that many would be

away from the settlement. However, the scientists adjusted by spending half their time interviewing elders in the settlement and the other half on excursion trips, which facilitated contextualizing the knowledge shared about the changing environmental conditions. Likewise, Davidson-Hunt and O'Flaherty (2007, p. 298) used meetings with elders and other community members to understand the capacity of the project and its participants, reporting that "In light of the very different cultural and institutional expectations being made on the research, a fair amount of time was spent discussing what would be mutually acceptable for both parties to undertake given their very different institutional contexts."

Existing institutions provide the opportunity to enhance the capacity for co-production processes once the underlying socio-political dynamics of the knowledge systems are fully understood. Co-production research indicates that transformational change is most likely to occur through modest reconfigurations of existing knowledge and political arrangements rather than novel replacements (Muñoz-Erickson et al., 2017). Many of the case studies featured adjustments to their existing institutional networks, rules, and roles. For example, the experiment by Akpo et al. (2015) served as a multi-stakeholder platform that bridged the stakeholders in the oil palm seedling supply system in the process of social learning. This cooperation facilitated the participating research center in adjusting their training for nursery holders according to the needs of farmers, leading to changing practices across the supply system. In a different agricultural

case study, Kraaijvanger and Veldkamp (2017) discussed how the embedding, or institutionalization, of collaboration into the community was a factor that supported involvement as well as an output of the participatory experiment. They label this factor “group quality,” which was essential in gaining and keeping momentum. Another example of utilizing existing institutional frameworks can be found in the community discussions that followed environmental monitoring in Tanzania, which centered on better enforcement of existing local regulations, such as anti-littering laws, to promote a clean water supply (Shaffer, 2014). The monitoring presentations revealed illegal deforestation, which was affecting water security for the entire community. Nevertheless, community elders resisted punishing younger community members as they understood their lack of economic alternatives. This case study also demonstrates how, despite the environmental recommendations, the political leaders involved advocated transparency in the socio-economic context, the dynamics which ultimately determined the outcome.

New, flexible institutions offer an opportunity to foster the sustainability outcomes generated throughout the process of co-production. It is often necessary to produce both the service or knowledge and the social/governance mechanism for its implementation, thus the two products are co-produced together. For example, the Participatory Sustainable Waste Management project in Brazil created a management council of stakeholder representatives who plan and evaluate project

activities, discuss priorities, and deal with conflict (Gutberlet, 2015). The council was essential to progressing the group activities. This new institutional arrangement provided the deliberative, inclusionary means of governance for institutionalizing co-production, and thereby increasing its capacity, within waste management. In other words, the project went beyond identifying the need for recycler inclusion in waste management, it established the means for their inclusion in governance.

In summary, methods for building capacity and facilitating co-production by overcoming common socio-political barriers include:

- Early engagement with stakeholders helps to uncover the socio-political systems in which the co-production process is embedded. Initial assessments can be done through introductory field visits, community meetings, interviews, surveys, workshops, and conceptual mapping.
- Early relationship-building and flexibility can help identify and accommodate institutional and community dynamics that would otherwise impede the co-productive capacity.
- Building capacity within existing institutions through reconfigurations, such as re-evaluating laws or modifying agricultural production practices, is often more feasible in institutionalizing co-production processes and outcomes.

- In the lack of suitable existing institutions, new arrangements, such as a stakeholder committee, can help produce both the outputs and outcomes of the process.

Space Constraints

A potential challenge faced by co-production practitioners is finding a neutral, accessible space that enables socio-ecological knowledge to flow freely. Some institutional settings might be perceived as restrictive or closed, which can be counterproductive for encouraging inclusion and the sharing of knowledge. For example, in a study by Rosenlund et al. (2017), universities were regarded as closed systems that lacked channels accessible to other social sectors. Business, public, and industry stakeholders did not know how to gain access into the universities due to perceived barriers. Researchers were deemed preoccupied, difficult to contact, and challenging to communicate with. One representative from the public sector remarked that universities were not especially interested in making new contacts.

An additional challenge to collaboration exists when spaces embody the tensions that exist between different stakeholder groups. Conflict can predispose meeting spaces to inadvertently preclude other stakeholders from feeling welcome and able to share. For example, Pohl et al.'s (2010) case study of a biodiversity governance project in Tunari National Park, Bolivia, was the result of a conflict between indigenous Quechua communities and government authorities, each wanting to

determine the use of resources in the park. Quechua communities asserted their right to utilize the park's resources, whereas the state sought to maintain the biodiversity and functions of the park's ecosystems. Neither the indigenous or government facilities would be suitable for supporting knowledge exchange, as both were seen as spaces of hostility.

Spaces of conflict can preclude community members from participating at all. Davidson-Hunt and O'Flaherty (2007) drew attention to the difficulty in considering issues of conflict and inequality unless brought up by community participants or agencies. Such was the case with a community discussion among Tanzanian farmers that intensified during the topic of pests and diseases among livestock (Shaffer, 2014). The residents felt animosity towards nomadic pastoralists for stopping to feed and water their herds a number of years prior, which they believed contributed to the appearance of new cattle diseases. The conversation shed light on why nomadic communities were largely absent from the meetings; the space would not be a welcome one. As a result, a local stakeholder was absent from the project.

There is a tendency for co-production practitioners, especially those trained in traditional scientific approaches, to depoliticize the process by promoting a protective, 'shielded' institutional space, or insulated niche, that moderates outside forces (Boon et al., 2019). Doing so ignores political and social dynamics (Edelenbos et al., 2011) or attempts to eliminate constraints (Dilling & Lemos, 2011) that are subtly impacting

participation and will inevitably determine the outcomes. Despite co-production necessitating a safe, inclusive, and empowering space for participants to engage in the process, it is important to recognize that co-production, like any other knowledge-making process, is a political practice. If the goal is societal transformation for sustainability outcomes, then the historical and political context cannot be ignored. Shielded spaces do not reflect the true conditions of the surrounding socio-ecological context. Depoliticization contributes to the perpetuation of unequal power relations in co-production and other participatory processes. Political and power differences between participants are ignored to create a neutral space for consensus. This emphasis on consensus and integration as central tenets of co-production represents another mechanism of closing down the co-production process. It prematurely shuts down conflict and contestation, thus eliminating pluralism, informed dissent, and difference (Lövbrand, 2011; Turnhout et al., 2020). As a result, a balance must be maintained in fostering a space of sharing and difference that is not too abstracted from their lived realities. In doing so, the resulting knowledge and practices accurately represent the stakeholder's views and experiences, and the process opens the possibility of empowering participants beyond the confines of the project.

Space Opportunities

There exists a range of institutional spaces that enable co-production and the interaction of knowledge and action, including physical spaces, organizations, and collaborative social networks (Campbell et al., 2016; Muñoz-Erickson et al., 2017; Muñoz-Erickson & Cutts, 2016). Frantzeskaki and Rok (2018, p. 48) define multi-stakeholder engagement spaces as "institutional spaces in which multiple actors convene to allow exchange of ideas, dialogue on issues and solutions and interactions concerning targeted problems and their proposed solutions." Different organizational forms include boundary organizations, bridging organizations, and hybrid organizations. Similarly, different collaborative network configurations offer spaces in which knowledge co-production can occur, like knowledge-action networks (Muñoz-Erickson, 2014), knowledge systems (Cash et al., 2003), and communities of practice. These co-production spaces are not exclusionary, so communities of practice can take an organizational form just as networks can include a variety of organizations or individuals (Campbell et al., 2016). Effective linkages among social actors, organizations, and levels of governance provide the channels for continuous flows of information, shared understanding, and problem articulation (Armitage et al., 2009; O. Young, 2002).

Existing networks of actors, boundary organizations, and other institutional spaces, can greatly facilitate the process by providing a

familiar space where the focus can shift to new knowledge production. The participatory experiment by Kraaijvanger and Veldkamp (2017) took place in the institutional setting in which the farmers live and practice—their neighborhoods. The scientists designed the project so that each of the 16 participant groups consisted of neighboring farmers to facilitate the feasibility of long-term cooperation that might endure after its completion. They saw the community of practice as a positive setting for the forthcoming delegation and intensification of responsibilities among the farmers. Connections within the social network enabling co-production and participatory experimentation were already secured and logistical constraints would be minimized (Kraaijvanger & Veldkamp, 2017).

These supportive spaces resemble Davidson-Hunt and O'Flaherty's (2007) place-based learning communities (PbLCs), which are dialogic networks designed to develop supportive relationships and cross-cultural understandings on local issues in the efforts to build capacity for people to address their own needs and co-produce locally relevant knowledge. Social spaces are effective platforms for sharing knowledge and experiences over a common problem. They open communication pathways for otherwise hostile and disparate groups to interact and better understand other perspectives (Shaffer, 2014). For example, in the case of the project in Tunari National Park, Bolivia, researchers from the Agroecology Program of the University of Cochabamba (AGRUCO)

carried out the research, providing a neutral, protected meeting spot as an alternative to their respective conflict-ridden domains.

Different forms of social spaces, such as social networks, can stimulate learning through the sharing of knowledge and experiences. Cooperatives are formal or informal associations composed of users who share the planning, designing, and delivering of co-production services (Bovaird, 2007). They provide a network of information flows and social capital to foster collective organization and action that transcend boundaries, empowering community members who would otherwise not have access if working alone (Castellanos et al., 2012; Gutberlet, 2015). In the case study by Gutberlet (2015), recyclers are self-organized in informal cooperatives and other networks to collect, separate, and sell recyclables, with or without government support. The recycling cooperatives in Brazil provided a link between the recyclers, researchers, municipal governments, and nongovernmental organizations (NGOs) for the co-production project to commence. Representatives of the cooperatives served as participants from the recycler community, and they remained the most active of the stakeholder groups, vocalizing the enduring challenges of engaging with their local governments.

Pre-existing projects can lead to the opportunity to merge co-production projects, thus providing a familiar space with established relationships, trust, and resources. Integration with an established project has several benefits: potential to build on the study and widen its

application and exposure; avoided repetition of learning exercises; focus can be directed to the needs and gaps already identified; additional gained community interest and support; no unnecessary duplication of resources; and respect for the community's limited time and capacity for engagement (Kench et al., 2018; Pearce et al., 2009). Kench et al. (2018) identified another project with complementary objectives to the Edge project, with the added bonus of providing a practical decision-making process in which the project could be embedded, providing the impetus for co-production within coastal management to take place. Similarly, Pearce et al. (2009) joined their Arctic Bay-Igloolik project with a similar study in the same community recording local observations of climate change.

In the absence of existing networks or projects to build on, new co-productive spaces must be forged across sectors (Raymond et al., 2010) and scales (Castellanos et al., 2012) to enhance institutional capacities through new relationships and modes of interacting over a shared environmental issue (Davidson-Hunt & O'Flaherty, 2007). The joint experiment by Akpo et al. (2015) included the system of stakeholders involved in the oil palm seedling production in Benin to determine the most effective production techniques. Prior to the learning experiment, nursery holders in the same community seldom had the opportunity to collaborate and learn from each others' production difficulties. The co-production process opened a space for them to meet and exchange their experiences, insights, and concerns to improve practices. Akpo et al.

(2015) contends that participatory experiments are ideal spaces for testing new technologies while the capacity of local conditions is evaluated and new knowledge and ties are co-produced. Similarly, Castellanos et al. (2012) forged new networks among coffee farmers in four Latin American countries to share their traditional practices and local ecological knowledge.

According to van der Hel (2016, p. 169), “knowledge production should not close down questions of meaning and value, but rather allow for inclusive and open deliberation of issues of societal concern.” By resisting the hasty closure of differences and conflict, co-production offers a space for views to be expressed openly without fear of being suppressed because they don’t align or may contradict project goals. This unrestricted space of negotiation brings to light the objections, issues, and realities faced by participants, which can be further analyzed to uncover the contexts and capacities discussed in previous sections. For example, Gutberlet (2015) describes the patience necessary to negotiate solutions in the Participatory Sustainable Waste Management (PSWM) project, as the local recyclers were finally being given a platform to voice their experiences, which was emotional. The open, inclusive space allowed for tears and anger to be expressed, and as a result, all participants (university, government, and recyclers) conveyed the value of their participation and the outputs.

In conclusion, effective spaces for collaboration are a crucial factor in the capacity for co-production, particularly in cases of highly contested environmental resources. Important considerations and paths for creating spaces conducive to community inclusion involve:

- Familiar social spaces, such as neighborhoods and cooperatives, have existing social ties that are beneficial to collaboration and ensure the continuity of co-production beyond the project.
- Merging with pre-existing projects offers a space with established social and resource infrastructure that can allow co-researchers to shift their focus to knowledge mobilization.
- New spaces can provide networks for participants to meet and exchange their experiences, insights, and concerns. For example, meetings with rural farmers that previously did not interact can help build relationships, or nodes in a social network (spaces), to better facilitate information flows.
- Spaces that allow and encourage difference will open up the process to a plurality of perceptions and experiences that were previously unheard.

Timing and Funding Constraints

Effective co-production, in terms of both participant satisfaction and outcomes, requires adequate resources and time, which can be significantly more than those required for more limited modes of

engagement (Cvitanovic, Hobday, Van Kerkhoff, et al., 2015). A total of ten out of 13 of the articles mentioned challenges associated with the time and money required for multi-stakeholder projects. Time is needed to build rapport and trust and adequate funding should provide financial assistance. It took eight years of a 14-year-long research project for researchers to demonstrate the validity of the research and gain the trust and enthusiasm of the entire community of Rakiura Maori tītī (*Ardenna grisea*) harvesters (Moller et al., 2009). Changing attitudes among the birders in one community forced researchers to relocate the research to another community and rebuild relations and benchmark studies, which meant that some of the researchers were restarting again in year four of the project. Funding is understandably challenging when one of the requirements for co-production is that the process remain open-ended and subject to change. Such flexibility is not built into current funding paradigms, where rigid methodologies and outputs are the norm.

A co-production approach requires the researcher to commit the time and resources to support the process rather than physical, quick results. This additional commitment is unlikely to be rewarded in existing academic and research institutions less interested in the process than in streamlining research outputs (Davidson-Hunt & O'Flaherty, 2007). Conventional, fixed scientific and funding timelines lack the flexibility to accommodate the social commitments and cultural obligations commonplace to community life (Cullen-Unsworth et al., 2012). The

contractual model of funding organizations prioritizes the achievement of milestones and results in a time-bound manner (Kench et al., 2018). Co-production in academic and corporate contexts lack the profit incentives and rewards that might make this work attractive to their metrics of success (Podestá et al., 2013; Sutherland et al., 2017). A study by Nicotera et al. (2011) revealed that increased funding for community-based research by universities energized faculty and generated feelings of excitement and passion, while simultaneously elevating the University's public image. However, upon reflection of the project and the additional time and energy needed for its completion, researchers expressed concerns in reconciling their long-term community commitments with the traditional academic reward structure. Their promotions and tenure depend on the production of research and publications that outpace community engaged work (Nicotera et al., 2011).

Strictly bounded time frames, such as policy and funding cycles, can alter who is involved, when, and to what extent. Institutional funding opportunities and time frames represent a critical barrier to the advancement and widespread adoption of co-produced projects. Gutberlet (2015) attest to the difficulties university administrators had formalizing partnerships with research institutes and remitting funds in the required time frames. In addition, limited time frames and funding can pose constraints on researcher visits to communities, especially in remote settings. For example, travelling to the Arctic communities was both time

consuming and expensive for Pearce et al. (2009), which posed challenges to local involvement in the initial design and development of research. Furthermore, the hunting seasons of Arctic indigenous communities shaped the research time frames of the Arctic Bay-Igloolik study (Pearce et al. 2009), as many hunters would be closer or further away from the settlements. Researchers from university settings often plan their fieldwork to occur during non-teaching parts of the year, which may not coincide with the availability of community members (Pearce et al., 2009; Wolfe et al., 2007).

Since universities typically do not have the resources to provide social assistance for research programs (Castellanos et al., 2012), inadequate funding could limit interactions with communities and other stakeholders (Adams et al., 2014). A study by Bromham et al. (2016) analyzed 18,476 proposals that were submitted to the Australian Research Council's Discovery Programme over five years, and found that the greater the degree of interdisciplinarity in projects, the lower the probability they had of being funded. This could discourage researchers from attempting co-production projects with communities, or in including other fields, such as the social sciences which could assist community interactions. Cullen-Unsworth et al. (2012) draws attention to the lack of resources available to engage indigenous peoples in Australia that led to dismantling the Aboriginal Rainforest Council, which was central to facilitating the co-production project. Cullen-Unsworth et al. (2012) point to

inadequate resources as illustrating the persisting marginalization of indigenous communities and lack of support for their inclusion in research and management settings.

Central to the concept and practice of co-production is the exchange of knowledge, which infers a multi-directional process of reciprocity and mutual benefits; missing from this exchange is the equitable appreciation of the different knowledge forms, which is a barrier potentially exacerbated by limited resources (Fazey et al., 2012). Financial compensation can be problematic for a number of reasons: inadequate grant funding to offer financial incentives to participants (Castellanos et al., 2012); money as a source of contention between researchers and communities that hamper relationship building (Moller et al., 2009; Pearce et al., 2009); and potential dependency on finite funds (Kraaijvanger & Veldkamp, 2017). Both Moller et al. (2009) and Castellanos et al. (2012) report the challenge faced by paid researchers telling communities they will not be reimbursed for sharing their knowledge. Rakiura Māori communities expressed resentment towards the perceived imbalance of benefits for their contributions, including the unrequited sharing of knowledge and lack of compensation (Moller et al., 2009). Without remuneration, participants are expected to invest their personal and/or professional time, which limits the scope of stakeholders to those able to volunteer their time. Communities are willing to participate in projects if they perceive value in doing so, which can be in the form of new

knowledge, enhanced relationships and communication pathways, and/or financial compensation. Each stakeholder should find value in participation, whether that be social or economic support. The appreciation of knowledge must go both ways, and communities should receive benefits that adequately reflect their contributions, as they understand them.

Timing and Funding Opportunities

The challenges of obtaining the necessary resources for co-production projects also presents the opportunity to develop novel research programs to support community-driven projects. For example, the Edge project by Kench et al. (2018) was funded by the New Zealand government through a research initiative, titled Resilience to Nature's Challenges (RNC), which was dedicated to enhancing New Zealand's resilience to natural hazards. Co-production formed a central tenet of the program, ensuring multiple actors in all stages of the process. After several days of collaborative workshops, the researchers submitted an open, flexible proposal in anticipation of shifts in the objectives and methodologies following wider stakeholder input. The funding agency welcomed the flexibility to accommodate the uncertainties inherent in the co-production process. Nevertheless, the proposal contained clear research objectives, milestones and objectives to fulfill traditional funding requirements. Therefore Kench et al. (2018) maximized flexibility and the capacity for local input while still operating in a traditional funding system.

If possible, leaving the funding flexible allows for unexpected, yet promising, research initiatives to be pursued. Similarly, funding for the Mesoamerican coffee project came from an agency that advocated diverse communication approaches and forms, which allowed for the hiring of an external communication consultant in the absence of this expertise (Castellanos et al., 2012). These funding models help to build the capacity for co-production work, as well as the resilience of communities by integrating their voices into defining the environmental problems and solutions that impact their lives.

Financial compensation, either directly or indirectly through local employment, is one means of expressing gratitude, incentivizing participation, and ensures the community perceives the project as a reciprocal exchange. The project design should reflect any time and funding limitations and make clear if and how community members and other actors will be remunerated for their participation from the outset (Davidson-Hunt & O'Flaherty, 2007). First and foremost, the method and amount of compensation should be consistent with culturally appropriate procedures for repayment. Local governing bodies and research organizations can help guide researchers in establishing fair and suitable payment to communities (Pearce et al., 2009). Kraaijvanger and Veldkamp (2017) provided a per diem for every time they participated in a workshop (plus a lunch), and farmers hosting the experimental fields received compensation for yield losses. These were calculated using the

regulations of the Bureau of Agriculture and Rural Development (BoARD). Similarly, Pearce et al. (2009) determined financial compensation rates for each of the three Arctic projects in collaboration with the Northern research institute in each study region. Remuneration supplants the time participants take out of their schedules to partake in the research, which helps offset the money they would otherwise be earning through employment, farming, hunting, fishing, and other income-generating activities.

Another means of community support is by providing local employment for community researchers, interpreters, and guides. In the Ulukhaktok study in Arctic Canada, community representatives redirected the research budget to hiring two local high school graduates as research assistants rather than taking financial compensation for interviews and meetings (Pearce et al., 2009). Over the course of the 14-year long Tītī Project, scientists trained three Māori PhD students, one Masters student, and one Honours student, enabling the involvement of their youth in local science and encouraging science capacity building (Moller et al., 2009). In addition, the project hired two long-term Rakiura Māori research assistants and managers, and a further six community members were hired for short-term fieldwork. Training and employment opportunities contributed towards building scientific capacity within the communities. In the Arctic case studies, employment of local researchers from the study communities was a key element in maintaining effective communication

(Pearce et al., 2009). These employment opportunities helped garner local support for the research and participation by some who would not have been included. Local co-researchers reported numerous benefits associated with these opportunities, including learning research skills, subsequent employment on other projects, and courage to pursue further training.

Resource inputs, if minimal, present the opportunity to build capacity within the community to sustain efforts long after project completion. If the outcome and application are expected to extend beyond the project deadline, value of participation must be built among the interacting sectors that perpetuates long after the researchers leave. Kraaijvanger and Veldkamp (2017) advises minimizing external material and cognitive inputs in order to reduce the potential for dependency, which decreases the sustainability of participation. Therefore, researchers served as facilitators and the farmers were paid only for their time spent at workshops. This model seems fitting in cases of participatory experimentation and monitoring (Akpo et al., 2015; Kraaijvanger & Veldkamp, 2017; Shaffer, 2014), but in more collegial modes of co-production (where knowledge inputs are coming from diverging sources, and the outputs are also going to different parties), community members may have jobs and other commitments that would likely have to be diverted to participate. In addition, their inputs of socio-environmental

knowledge is their intellectual property, which has been handed down through generations and thus has deep cultural value (Moller et al., 2009).

In the absence of financial support, opportunities exist in providing non-monetary support. Value must be established in the knowledge that will be shared and learnt throughout co-production. Without funds to provide social assistance to coffee farmers participating in the project, Castellanos et al. (2012) had to focus their efforts on building the farmer's appeal to participate with only new knowledge and connections to offer as an incentive. They highlighted the project's application in numerous countries, and the potential to share the experiences of other farmers across Mesoamerica. They offered information sessions and reports that would also be shared with local authorities and policymakers. Many of the communities, in Chiapas, for example, saw the benefit of learning about the coping strategies of other farmers grappling with the current climate and economic induced coffee crisis. Communities, organizations, and governing bodies at the different project sites identified the results as essential to intervention strategies that should be shared with their decision-makers. Shaffer (2014) provides another instance of innovative support for community participants who sought additional tools for monitoring the quality of communal water sources. Due to budget limitations, researchers were unable to supply the additional materials or methods, but instead offered an educational seminar on the water cycle and water purification methods using low-cost, locally sourced materials.

This example demonstrates the positive feedback loops that can result from co-production, whereby community mobilization and social learning generates additional manifestations of community enhancing capacity to monitor and evaluate local socio-ecological conditions and then intervene in ways that enhance community well-being (Kofinas, 2009; Minkler et al., 2008).

In summary, despite an overall lack of incentives for community engagement, opportunities exist for building the capacity for co-production in regards to timing and funding, which include:

- New research institutions, programs, and initiatives that emphasize community-driven processes can afford the flexibility, resources, and time that accurately reflect true 'participation.'
- Financial compensation and local employment opportunities should be built into the funding proposal to support the equal distribution of benefits.
- On the other hand, minimizing resource inputs can minimize dependency and build non-monetary value in the process to ensure its continuity. Instead, scientists can emphasize new knowledge products, social connections, information sessions and workshops, access to policymakers and input in decisions, and strategies for reducing socio-ecological vulnerabilities

Facilitation Constraints

A common hurdle is the lack of institutional resources and training to equip early career researchers with the competencies needed to facilitate the process (Castellanos et al., 2012; Moller et al., 2009). Access to interdisciplinary programs is growing, but institutions largely remain siloed. Moller et al. (2009, p. 235) noted “effective research partnership with Māori requires personal adjustments, self-reflection and unimagined challenges not yet encountered by most scientists.” The capacity for co-production work often hinges on the ability of scientists to anticipate challenges, span institutional boundaries, and guide the process from start to finish. Akpo et al. (2015) emphasized the necessity of facilitation skills to curb any attempts by participating stakeholders to commandeer the research. Pohl et al. (2010) elaborated the three different roles that sustainability researchers must fulfill: that of the reflective scientist, intermediary, and facilitator. They attribute the success of scientists in guiding the projects to having worked as a practitioner in the past. They recognized that the skills learned in social sciences, such as anthropology, that enable collaboration with multiple, unknown viewpoints and tacit knowledge are not a formal part of training for sustainability researchers.

Researcher expertise is often limited to one discipline and/or geographically concentrated, which can pose challenges to spanning scales and disciplines. For example, the project by Castellanos et al. (2012) took place across several Mesoamerican countries and featured

social and natural scientists who shared previous experience working in some facet of coffee production. However, they report contending with epistemological bias and geographically concentrated expertise, where some researchers were expected to carry out all parts of the project in their own region despite low competence. According to Castellanos et al. (2012, p. 8), “Research institutions often consider applied work as less valuable than theoretical work, and communication activities receive little consideration in tenure and promotion processes.” They lacked the training and personnel to facilitate research activities and communicate the results to communities and policymakers (Castellanos et al., 2012). This posed a critical barrier to their co-production project and reduced their capacity to meet one of their objectives of generating usable information for decision-making. Their preferential selection according to researcher networks resulted in irregular degrees of detail across the data. They largely attributed their project failures to not prioritizing developing deeper relationships with boundary organizations that could have facilitated their process.

Facilitation Opportunities

The co-production process is contingent on facilitation, which can be done by a participant or organization. Participants facilitating co-production are often called ‘boundary spanners’ or ‘information brokers’ due to their epistemological agility and skills in bridging different communities of practice (Ferguson et al., 2014; Harris & Lyon, 2014).

They enhance the process by bringing together diverse cultures, facilitating dialogue, and building and sustaining relationships (Cvitanovic, Hobday, van Kerkhoff, et al., 2015). It is important to recruit researchers able to straddle disciplines and bridge the often conflicting agendas of different stakeholders (Simon et al., 2018).

A study on successful interdisciplinary community collaboration (ICC) strategies by Bayne-Smith et al. (2008) found that community organizers must have certain strategic planning, administrative, and intra- and interpersonal skills, as well as sets of values and attributes, like cultural competency. Every article discussed the importance of facilitation to their research process, and eight of them expound the requisite skills needed by researchers to maximize co-production success. For example, Moller et al. (2009) relays the competencies of an 'ideal' scientist described by the local Rakiura people, such as respect, a sense of awareness, open mindedness, humility, and cultural sensitivity. The project scientists had to "learn a new range of skills, to give over a huge measure of control of the research process, to deal with conflict, and to make themselves personally accountable for their science" (Moller et al., 2009, p. 225). In designing and implementing a joint experiment among stakeholders in the oil palm seed system in Benin, Akpo (2015) stresses the need for facilitating and management skills for a process inclusive of actors from different backgrounds and authority. Understanding these basic competencies reported by co-production projects provides a

baseline of the skills that could be emphasized in new training programs and classes. As interdisciplinary graduate programs grow in popularity (i.e. University of Maryland's MEES Environment and Society foundation), new researchers will be better able to traverse traditional boundaries and work with non-scientist stakeholders.

Networks of community organizations and research institutions are available to assist researchers, and in many indigenous settings have a mandate to do so (Pearce et al., 2009). Coordination and facilitation can be accomplished with other governance structures across multiple contexts and scales from informal individuals and organizations to formal governing bodies (Cullen-Unsworth et al., 2012). Community governance bodies and systems can serve as reputable conduits for communication and institutional continuity in co-production (Kench et al., 2018; Pearce et al., 2009; Moller et al., 2016; Gutberlet, 2015). Multi-level indigenous governance and regional Aboriginal organizations were identified as playing a key role in the WTWHA project, as they initially guided research activities and subsequently governed the research process (Cullen-Unsworth et al., 2012). The Aboriginal Rainforest Council's Intellectual Property Subcommittee held responsibility for the research, directed the research activities, and ensured the project remained culturally appropriate. According to Pearce et al. (2009), initiating contact through existing indigenous organizations and research institutions ensures that accepted protocols for contacting and engaging communities are being

followed, which helps reduce potential conflicts while establishing research legitimacy.

More formal stakeholder organizations often serve as boundary organizations that are place-based, but situated in multi-scalar networks of environmental practitioners. Boundary organizations are intermediary organizations that bridge different communities of practice and facilitate their interactions and exchange, or broker knowledge (Briley et al., 2015; Kirchhoff et al., 2015; Nel et al., 2015; Wyborn, 2015). They might be primary means for supplying environmental data and technology to practitioners, or coordinating learning activities. A leading member of the Honduran Coffee Institute (IHCAFE) facilitated the initial introductions between researchers and coffee growers (Castellanos et al., 2012). Their members and staff are in a position to nurture learning processes as they have the trust and communication insights for valuable assistance to researchers starting from scratch. Inclusion of these groups will lead to enduring relationships, flows of information, and project benefits long after its completion (Davidson-Hunt & O'Flaherty, 2007).

In conclusion, facilitation is critical to co-production and in the absence of adequate training or personnel, opportunities are still present for practitioners to successfully navigate the process, including:

- New training programs (or revisions to traditional ones) can integrate the competencies reported by co-production

projects to outfit newer researchers with the skills to facilitate community collaboration.

- Community organizations and regional research institutions are often better equipped to facilitate a co-production process. These can include local governing bodies and boundary organizations.

Power and Inclusion

Co-production processes are political and ethical undertakings that fundamentally reshape science and its social authority, which are inherently power-laden and run the risk of exclusion (Mach et al., 2020; Miller & Wyborn, 2018). Co-production in environmental research is a concept that embodies both the analysis of knowledge generation in response to environmental and institutional dynamics, and the direct, participatory challenge to them. The commitment to partnership and iterative participation deconstructs and challenges conventional distinctions between the researchers and those being researched by democratizing the knowledge production process and deprivileging notions of expertise. However, the normative co-production literature of guidelines, conditions of success, and lessons for practice often pay scant attention to why processes fail (Wyborn et al., 2019), the underlying role of power and politics (Turnhout et al., 2020), and with whom the process should be inclusive (Frantzeskaki & Rok, 2018). Co-production practitioners who see the process as a means to galvanize scientific

knowledge to solve global and scientific problems tend to focus less on the power dynamics imbued in the process (Bremer & Meisch, 2017; Lövbrand, 2011; Turnhout et al., 2020). These not only pose significant challenges to co-production, but if ignored can exacerbate the problems trying to be rectified.

Pohl et al. (2010, p. 271) defines power as “having the ability and the resources to negotiate and adapt interests during the process of knowledge co-production.” Power can take any number of concurrent forms: “knowledge to influence policies (knowledge power); competencies in utilizing data (information power); stakeholders’ capacities (technical power); and access to resources (economic power)” (El Ansari, 2005, p. 766). These forms of power are manifested in the relationships and activities guiding the co-production process and outcomes. Ten of the 13 articles brought up power in some capacity. The following sections identify the common challenges, representation and knowledge, associated with power dynamics that preclude community inclusion in both the process and outcomes, as well as the opportunities by way of deliberate actions that practitioners in the case studies took to identify and mitigate them. The first two sections look at the constraints and opportunities related to equal representation in co-production projects’ objectives, activities, and inputs and outputs. The subsequent sections focus on the power dynamics surrounding the divide between scientific and traditional

knowledge systems, the expression of which can be evident in co-production processes.

Representation and Participation Constraints

A common barrier to co-production is identifying with whom to engage. More attention is needed for defining the "diversity of actors and relationships involved in the process by which knowledge is produced." (Agrawal, 1995; Davidson-Hunt & O'Flaherty, 2007, p. 293). This raises key implications about representation pertaining to whose voices should be heard and whether some stakeholders have the authority to represent certain groups. If some stakeholders are not represented, participation reverts to mere tokenism (Frantzeskaki & Rok, 2018). Co-production would benefit from a better understanding of the mechanisms that successfully empower individuals while shedding light on the ways in which such mechanisms can be embedded within larger efforts for sustainability.

In aiming for actionable knowledge that contributes to environmental solutions, co-production practitioners emphasize the inclusion of leaders, executives, decision-makers, and other individuals to represent the interests of constituents, customers, and other citizens not in a position of power. Communities that lack political representation and are unable to self-organize are thereby excluded (Turnhout et al., 2020). Emphasizing the inclusion of actors who hold prominent or influential roles in society reinforces the preclusion of more peripheral actors whose

voices have been neglected. Terms put forth by the Future Earth initiative reflect such disenfranchisement: “The societal actors identified as possible partners in knowledge co-production are those actors that are in a position to ‘make a difference in society’” (van der Hel, 2016, p. 169). With their logic, those incapable of making a significant difference, often due to their already disadvantaged position, are dismissed as a potential partner offering a meaningful contribution to sustainability. In effect, the production of knowledge that has utility to those already in power can institutionalize problems and reinforce elitist relationships, thus further marginalizing people with reduced capacity or variant positions (Wyborn et al., 2019). Participation biases in favor of elite actors not only denies access to local community members in the process, they diminish the resonance and usability with communities and thus impact the the quality, usefulness and legitimacy of the co-produced outcomes (Schmidt & Neuburger, 2017; Turnhout et al., 2020).

Tailoring a project to the usability of some stakeholders, such as policymakers, creates boundaries for the knowledge, including what is considered feasible and desirable (Lövbrand, 2011). Usefulness to policy practitioners means co-production is held accountable to existing policy goals and agendas, which can “close down” the process, rather than open the knowledge system to re-examining dominant assumptions (Frantzeskaki & Rok, 2018; Lövbrand, 2011). This is not to demote usefulness as a worthy endeavor, only that practitioners must proceed

with caution in maintaining a level playing field of demands, value, and use among all stakeholders. In tailoring the process to the needs of policymakers, this elite group is being given the power to determine what counts as useful and legitimate knowledge. By equating the value of research to its potential usefulness for user groups, co-production risks "reifying the instrumental forms of co-production that scholars of science and society are so eager to challenge" (Lövbrand, 2011, p. 227). In other words, rather than supporting innovation and learning, co-production turns into a mechanism for reinforcing the knowledge hierarchies and exclusionary practices that its practitioners set out to challenge in the first place. Resources and demands are thus leveraged to transform what started out as a noble pursuit into an initiative designed to serve political agendas.

Choosing participants from pools of elite actors calls into question whether those individuals are the appropriate representatives for local groups, and whether co-production actually engenders taking a 'bottom-up' model for research and management. Elites, such as those from governments, NGOs, and research institutions, have the disproportionate ability to shape the co-production process as they "have more time and resources available, often initiate these processes, define the scope for participation, have more knowledge and skills, and are, for all these reasons that resonate with social-cultural biases, better able to articulate a

contribution that is considered relevant and important" (Turnhout et al., 2020, p. 16).

Furthermore, resources, or lack thereof, can affect the perceived accessibility to the participatory process and other actors. Disparate resources can widen the gap between participants and their levels of trust and assumed equality. For example, Castellanos et al. (2012) writes about the difficult time researchers had balancing the expectation of farmers with their perceived differences in privilege and power, including their access to mobility, knowledge and information, and financial resources. Power relations and constructs of the 'other' are accentuated further by the fact that the elite participants are typically paid for their contributions, whereas it is presumed that other participants will volunteer their time and services. This limits the pool of people available to take part. As a result, those with more power and resources could potentially take advantage and undermine the co-production process (Turnhout et al., 2020).

Raymond et al. (2010) identifies a key barrier to addressing power is rooted in funding. The scope and objectives of funding opportunities frame the proposal development, stakeholders involved, and methodologies used (Podestá et al., 2013). Most projects have external funding, such as through a research or non-governmental organization, therefore the "local knowledge framing problem identification largely sits in the hands of the scientific knowledge holders and thus application of the results ultimately rests with them" (Raymond et al., 2010, p. 1774).

Raymond et al.'s Uplands and Otways projects were the two least inclusive case studies. Although they included communities, their representation in the scope and engagement approaches still largely reflected scientific dominance.

The literature often cites the difficulty of ensuring all relevant stakeholders are included in the co-production process so that the research does not reinforce exclusionary practices (Frantzeskaki & Rok, 2018). Although existing social networks can be advantageous in easily locating different stakeholders, there is the added challenge of making sure relationships are unbiased, such as those between researchers and policymakers, and that the network is comprehensive of those involved. Those with pre-established relationships and extensive social networks throughout the science, policy, and local communities are preferentially invited to participate which can introduce bias and preclude more informal, marginal actors (Frantzeskaki & Rok, 2018; Turnhout et al., 2020). Selecting stakeholders based only on the most accessible, visible, and well-resourced members of a community might overlook a key demographic and local conditions. For example, the case study by Gutberlet (2015) illustrates how prior to the project informal recyclers in São Paulo, Brazil were largely excluded from participating in sustainable waste management. Workers in the informal recycling sector help reduce the waste disposal burden for cities by as much as 20%, yet their livelihoods often go unrecognized by governments and communities and

their social, environmental, and economic contributions remain largely unacknowledged (Gutberlet, 2015; Wilson et al., 2006). In Brazil alone, between 500,000 and one million people work as informal recyclers. However, waste management seldom takes a participatory approach by including the informal sector, instead favoring engineer-run operations (Gutberlet, 2015). A co-production research project on waste management in São Paulo might unintentionally exclude participation from recycling cooperatives if researchers rely on existing, formalized operations without identifying *all* stakeholders at the project's start and the social dynamics that may interfere with their participation.

Some participatory approaches maintain central authority and purport contractual levels of engagement with non-scientist stakeholders at some point in the research process, sustaining the assumptions and practices of traditional scientific models (van der Hel, 2016). Researchers or government agencies will 'consult' with local people, yet the priorities, actions and solutions are already established (Moller et al., 2009). For example, Kraaijvanger and Veldcamp (2017) summarize previous participatory experiments with farmers and scientists, finding a lack of involvement as most farmers were asked to only provide information or validate pre-selected choices. Although the very act of collaborating with nonscientists challenges traditional research processes and roles, some approaches to participatory knowledge production remain steeped in traditional, top-down, exclusionary practices. For example, the

researchers in the Sustainable Uplands project in the UK limited their methodologies to semi-structured interviews and questionnaires that were designed to collect answers to research questions only (Raymond et al., 2010). Although a wide range of local land managers, such as farmers and game keepers, were included, this project was one of the least inclusive of the 20 projects. In cases such as these, participation is a misnomer for research approaches and methodologies that are reifying exclusion. Co-production that integrates communities haphazardly, or not at all, can end up reinforcing, and even exacerbating, the unequal power relations pervading the knowledge systems co-production seeks to transform. This leads to counterproductive outcomes that do little for furthering sustainability. Equality is not definitive of participation, and that raises questions about *how* all voices can be heard and embraced within the process in a meaningful and legitimate way (Turnhout et al., 2020).

Communication and cultural differences can pose a barrier to mutual understanding and participation. Communication was identified by every case study as essential to their co-production process. For example, Castellanos et al. (2012) discussed the fact that women largely stay silent in the company of men and strangers, and they did not speak the same language as the research team, Spanish. Interpreters and locals helped bridge the communication gap, but limitations to mutual understanding and communication remained. Translation also made their analysis of recorded information challenging. Communicating the results to other

audiences, besides researchers, can represent another barrier to the process, but this step is fundamental for inclusive outcomes. Pearce et al. (2009) reflected on the communication issues faced by scientists working with indigenous Arctic communities. The literal translations of the local languages, Inuktitut or Inuinnaqtun, make little sense in English, and vice versa. Differences in concepts, cultural framings, and word selection had to be reconciled with a skilled interpreter who could communicate the meanings in either language. There are additional logistical challenges to communication. The three Arctic projects faced problems with maintaining interactions when researchers left the Inuit settlements. Inaccessibility to communication lines, such as a telephone or the internet can pose a barrier to iterative dialogue. Still, shortcomings exist in projects when these are available, as miscommunication can occur over the phone and there are limitations to conveying messages over written communication.

Representation and Participation Opportunities

Since the representation of stakeholder needs and priorities is a central tenet to co-production (Reed et al., 2014), delineating ways to identify potential participants is of paramount importance. Participation by all community members is ideal for ensuring equal representation (and might be possible in small communities, such as in the Arctic), but likely not feasible, ergo, strategies for maximizing representation must be sought. The methods of outreach and stakeholder identification used by the case studies include: existing institutional structures and

representatives (Akpo et al., 2015; Cullen-Unsworth et al., 2012; Davidson-Hunt & O'Flaherty, 2007; Moller et al., 2009; Pearce et al., 2009), community meetings (Moller et al., 2009; Shaffer, 2014), previous collaborations (Gutberlet, 2015; Pearce et al., 2009), pre-existing researcher or community networks (Gutberlet, 2015; Kench et al., 2018; Kraaijvanger & Veldkamp, 2017; Pearce et al., 2009; Shaffer, 2014; Wolfe et al., 2007), regional organizations (Castellanos et al., 2012; Cullen-Unsworth et al., 2012; Pearce et al., 2009; Shaffer, 2014), and random selection (Castellanos et al., 2012; Kraaijvanger & Veldkamp, 2017; Raymond et al., 2010). For example, Pearce et al. (2009) attributes the researchers' early communication with national and regional Inuit organizations during preliminary planning as essential to identifying community research partners. In addition, the projects used a variety of other identification methods. In the Arctic Bay-Igloolik study, external researchers hired local researchers who had extensive knowledge of hunting to identify local experts and potential community interviewees (Pearce et al., 2009). In summary, there is not a formula for stakeholder identification, but using multiple methods is one way of reducing the risk of exclusion.

In total, 13 of the 20 projects featured community meetings to determine whom from the community would take part in the research and serve as their representatives. Of those, six did not report their methods for identifying stakeholders and representatives (Pohl et al., 2010;

Raymond et al., 2010), and only one project did not feature an initial community meeting for selecting researchers (Castellanos et al., 2012). In other words, the projects largely indicate that participation and representation should be decided from the community itself, not outsiders. Researchers in the Tanzanian environmental monitoring project identified potential participants through social networks of community leaders and organizations to invite men and women of all ages and backgrounds to an initial meeting at each of the four community sites (Shaffer, 2014). Researchers introduced the project, explained community-based environmental monitoring, and described current monitoring initiatives. The 20-35 community members decided amongst themselves which three environmental sectors to monitor, including crop health and production, quantities at local water sources (expanded to include tree growth and deforestation in two communities), and either fish production or livestock health and production. Each community also selected field teams of eight men and women for the monitoring program. The project aimed at designing linked biophysical and cultural indicators within the Wet Tropics World Heritage Area (WTWHA) began by reaching out to the regional Aboriginal governance system through which they identified and selected their own representatives across three communities (Cullen-Unsworth et al., 2012). Aboriginal organizations connected to community elders who would serve as brokers between researchers and scientists. One elder and one other local individual were nominated and elected as co-

researchers in each area. In both cases, the communities choose the respective researchers to represent them.

Understanding historical power disparities and their present-day effects will better shed light on the socio-cultural dynamics that may influence who participates in the co-production process. Special attention should be given to marginalized members of society that have not been adequately represented in past environmental practices and research. Gutberlet (2015) attributed the identification of historical hegemonies and the effects of power structures on the lives of project stakeholders as crucial to their research process. The author applies a lens of Post-Colonial and Feminist theory in recognizing that the informal recyclers in Brazil, many of whom are women, have faced social and economic exclusion and stigma through housing, education, training, and wages. Social hierarchies imposed during Brazil's colonial past have persisted and are now deeply ingrained within their social and governing institutions. Thus, it is important to not only identify all knowledge-relevant stakeholders, but also to examine the existing social systems without making any assumptions about their realities (Muñoz-Erickson et al., 2017). Identifying inequalities provides the opportunity to redistribute power among participants as equal contributors working side-by-side in equitable partnerships. Knowledge co-production requires that no one stakeholder group be privileged over another. Participation should enable

excluded individuals or groups to speak for themselves and take part in self-determined action and intervention (Gutberlet, 2015).

The concerns of community members should be just as valid and important as other participants. Seven of the 13 articles make explicit mention of the need for equal partnerships and input. Akpo et al. (2015) identified full, uninhibited involvement and equity among all stakeholders as essential to their learning experiment. Similarly, Moller et al. (2009) attributes the success of their partnership to equitable decision-making responsibility. One of the case studies by Pohl et al. (2010) demonstrates how the interests of farmers living in the Kangchenjunga Conservation Area of Nepal were given equal attention to the other two main stakeholder groups, the local government and conservation NGOs. The World Wildlife Fund's and government's declaration of the region as a protected area, and subsequent management regulations, prioritized safeguarding biodiversity over local livelihoods. The co-production project focused on reconciling the livelihood needs of local residents with the conservation interests of the government and NGOs. Farmers were concerned about the losses to their crops and livestock resulting from the resurgence of snow leopards and other animals, which was heralded by both the conservationists and public administrators. Local concerns were taken as seriously as the other two stakeholders, which warranted recognizing that the partnership between the state and NGOs, and subsequent declarations of protected status was preclusive and unjust.

The equal consideration given to both sides was imperative to overcoming underlying conflict and power dynamics, as well as guaranteeing equality and access throughout the project. Their equal inclusion and authority reinforced legitimacy to the process and outcomes. The collaboration resulted in a new community insurance scheme that compensates farmers for yak losses due to snow leopards, which prevents farmers from killing the leopards (Pohl et al., 2010). The new insurance scheme was a result of the collective input from all stakeholders and will likely lead to new management practices among the farmers.

Full participation necessitates the redistribution of decision-making power from professionals to community members (Arnstein, 1971; Cornish, 2006). The concept of empowerment shifts the discussion from 'power-over' to "power-with' and 'power-to' (Cornish, 2006; Hendriks, 2009). Empowerment and participation go hand-in-hand as communal activity and collectives incite 'power-with,' enabling individuals to processes they were otherwise excluded from. Therefore, the spaces and processes of co-production must empower community members to identify and use their agency to fully participate and contribute towards decision-making, especially in highly contested contexts of the environment and natural resources. Empowerment enables participation in accessing, providing, shaping, and defining the goals, activities, and services of a project (Cornish, 2006). An equitable partnership from the start requires empowering all participants as co-researchers in every stage of the co-

production process, which builds capacity to contribute and take part in decision-making long after project completion. As such, empowerment is both a requisite and outcome of participation in co-production. Gutberlet (2015) attributes participatory dialogue and brainstorming approaches on specific problems, as well as photovoice methodology, to the empowerment of recyclers in the PSWM project. Photovoice can enhance community engagement by putting “cameras into the participants’ hands to help them document, reflect upon, and communicate issues of concern, while stimulating social change” (Budig et al., 2018, p. 1). Photovoice is regarded as a methodology to facilitate co-production, where co-researchers document issues with cameras and the resulting photographs help direct interviews and community discussions (which was the case in an environmental management project about water values not included in the selected case studies) (Maclean & Cullen, 2009).

In endeavoring to achieve full participation, co-researchers should equally contribute to shaping the project scope according to their priorities and concerns. In total, 17 out of 20 projects feature community inclusion at the initial problem-framing through to disseminating the results. Most projects attributed trusting partnerships, transparent processes, and successful outcomes to joint problem-framing and early integration. For example, Cullen-Unsworth et al. (2012) credited their successful and engaging process to collaboratively defining the scope during initial ‘pre-research’ interactions. This built respect and support among participants,

fostered multi-directional learning, and secured reciprocal benefits and understanding. The Sustainable Uplands project in the United Kingdom featured site visits that were intended to bring participants together as equal partners to explore the uplands management issues they considered most important (Raymond et al., 2010). The outdoor environment and facilitation approach, according to Raymond et al. (2010, p. 1773), "significantly reduced the discrepancies in power that had been witnessed in previous workshops, as site visits were led by the land users themselves rather than the researchers."

Written agreements were established by many of the case studies to negotiate the roles, expectations, methods, and guidelines for engagement among all of the participants (Cullen-Unsworth et al., 2012; Davidson-Hunt & O'Flaherty, 2007; Kench et al., 2018; Moller et al., 2009; Pearce et al., 2009; Shaffer, 2014; Wolfe et al., 2007). These imbued their processes with transparency and helped delegate authority and redistribute power within the research teams. A memorandum of understanding (MOU) or other research protocol can address concerns about rules of research conduct, community benefits, and potential conflict resolution (Kench et al., 2018; Wolfe et al., 2007). Davidson-Hunt and O'Flaherty (2007, pp. 299–300) provide the elements of the research protocol that was negotiated with their research team, the people of Iskatewizaagegan No. 39 Independent First Nation (IIFN) in Ontario, Canada, which include: research mandate, project duration, preamble,

project summary, list of project partners and research team members, accountability, methods, compensation, review and dissemination of results, and archiving the research projects. These ensured the research was being conducted in a locally appropriate manner, while revealing some of the logistical and institutional dynamics framing the process. For example, listing all project partners disclosed all individuals and organizations involved in funding and carrying out the research, regardless of the extent of their influence.

Advisory committees provide an additional means for establishing accountability, resolving problems, ensuring continuity in representation, and encouraging openness (Davidson-Hunt & O'Flaherty, 2007; Raymond et al., 2010). For example, the Slave River Delta project in the Northwest Territories developed a steering committee to manage the traditional knowledge components of the research, guide the activities of external researchers, and ensure respectful interactions. Similarly, the Participatory Sustainable Waste Management (PSWM) project in Brazil established directing committees with deliberative power over the initiative, which served as a forum for discussing priorities, planning and evaluating project activities, and sharing knowledge through mutual learning to solve problems (Gutberlet, 2015). The committee was a collective process that facilitated stakeholders in voicing their perspectives that were typically not heard or challenged. Recyclers were empowered to take part in the local politics and discuss their rights.

Effective communication channels, in both language and interactions, help to redistribute power over interactions and participation, ensuring accurate representation and continual involvement. Ongoing, iterative communication, preferably in person, was identified by many of the case studies as an indispensable element of co-production. Seven of the articles mention ‘iterativity’ for the style of learning and communication necessary for sustained relationships and transparent processes. From the beginning it is necessary to identify a shared language, reduce scientific jargon, and establish consistent communication lines. Akpo et al. (2015) devoted attention to resolving language and other communication issues at the onset of the project. Participants were encouraged to use the local language, Nagot, rather than French since it was a common language for all involved. To ensure understanding, the local vernacular was chosen over scientific terms and concepts. This helped to address the various ways participants tacitly understood and expressed the practices being tested in the experiment. To accommodate illiterate farmers, the group used drawings to represent the different nursery practices that would serve as the experimental treatments. Kench et al. (2018) reiterates the value of face-to-face communication in developing personal understandings and stimulating learning. Outside of their biweekly meetings, project team members kept regular video-conferencing updates.

To summarize, equal representation and participation are an underlying tenet of co-production, and ways to ensure community access to the process and outcomes include:

- Methods for outreach and stakeholder identification within communities are varied and using as many as possible helps reduce the risk of exclusion. These consist of: (1) existing institutional structures and representatives, (2) community meetings, (3) previous collaborations, (4) pre-existing researcher or community networks, (5) regional organizations (help identify community leaders), and (6) random selection (in some cases of experimentation).
- Participation and representation should be decided from the community itself, not outsiders (i.e. non-local scientists).
- Co-production practitioners should take time to understand historical power disparities that may impact participation, ensuring all voices are heard.
- The concerns of community members should hold equal weight to those of other participants, therefore an agreed-upon middle-ground should be sought with collective input.
- Full participation necessitates empowerment of actors to take part in every stage of co-production. One way of doing so is through photovoice methodology.

- The project scope should reflect the equal contributions of all participants, and there should be mechanisms of accountability for enforcement. A prevalent strategy for doing so is to negotiate a written agreement, or MOU.
- Identifying a shared language and communication style will help ensure comprehension and agreement, and thus participation.

Knowledge Constraints

Co-production practitioners who seek to produce useful knowledge with decision-makers often make several assumptions about knowledge: that it takes a static form, such as a tool, model, or solution; that knowledge is something to be used (by predefined users) and disseminated for future decisions; and that it is easily understood and applicable to a wide variety of contexts and scales (Beier et al., 2017; Cash et al., 2003; Hulme, 2010; Latulippe & Klenk, 2020). These assumptions often reduce local and traditional knowledge to ‘data’ that can be infused within western scientific paradigms through transactional relationships (Latulippe & Klenk, 2020). Thus researchers try to extract only certain kinds of information that are readily applied to institutional frameworks within state and scientific resource management regimes (Nadasdy, 1999). Such a process involves distilling the knowledge out of the complex socio-ecological system, including the social relations and practices, in which it has meaning. In this context, powerful actors determine what is ‘known,’ legitimate, credible, and salient (Cash et al.,

2003; Hulme, 2010). As such, knowledge becomes a means to exert power. Instrumental forms of knowledge co-production that frequently emphasize the “integration” of knowledge types in ways that ensure salience, legitimacy, and credibility for decision-making ignore power asymmetries and cultural differences inherent in such a process (Diver, 2017; Goldman et al., 2018; Nadasdy, 1999). Co-production must wrestle with the challenge of preventing any one stakeholder group, such as researchers or government agencies, from dominating the knowledge flows within the process.

Western systems of science reinforce quantitative, analytical, technical, and reductionistic knowledge forms that rely on validity through its generation, documentation, and skeptical evaluation (Cullen-Unsworth et al., 2012; Nadasdy, 1999). Science prioritizes standardization and universality of “facts” at global scales through common practices of selection, deletion, ranking, and other unquestioned norms (Klenk et al., 2017). Local knowledge is instead rooted in place-specific contexts and is often regarded as qualitative, holistic and relational, where its validity is determined by its use and transgenerational oral transmission. The ontologies (being), epistemologies (knowing), and methodologies (doing) differ in these systems regarding the natural environment (Latulippe & Klenk, 2020). Early scholarship on indigenous knowledge treated the systems as unchanging artifacts to be discovered and documented, which is still a popular sentiment in methodologies attempting to capture the

knowledge for usable tools. This often leads to local knowledge being analyzed and cherry-picked to conform to ontological hierarchies within western science, effectively extracting local knowledge from the context and practices in which it holds value for adaptation (Klenk et al., 2017).

There has been upsurge in research approaches to harness traditional knowledge to interpret and respond to environmental changes and sustainability (Whyte, 2013). Assuming that simply integrating traditional knowledge with science will invariably result in improved management and empowerment of its holders ignores the power dynamics that pervade research with traditional knowledge, including co-production (Nadasdy, 1999). Practitioners of co-production that make this mistake risk “reinforcing, rather than breaking down, a number of Western cultural biases that in the end work against full community involvement in managing local land and wildlife” (Nadasdy, 1999, p. 2). “Integration” must be used with caution, as it implies the merging of knowledge systems through the assimilation of one knowledge type into another. In doing so, one knowledge type must undergo a validation process based on the requirements of the new host knowledge system (Tengö et al., 2014). It is most common to see the integration of traditional and local ecological knowledge into scientific knowledge, since the latter is assumed to have more legitimacy. The validation process and associated approaches can be argued as inappropriate, exclusionary, and disempowering for local communities (Nadasdy, 1999; Tengö et al., 2014).

In bridging different systems of knowledge, such as experiential and practice-based, co-production approaches necessitate epistemological and ontological pluralism, which challenges traditional, scientific notions of quality (Harris & Lyon, 2014). In settings dominated by legal and scientific experts, local participants are often viewed as unqualified or not 'scientific enough.' For example, two Dutch water management projects that attempted co-production with scientists, bureaucrats, and local citizens, demonstrates the values and credibility attributed to different knowledge sources (Edelenbos et al., 2011). The scientists and civil servants were unwilling to recognize the contributions and legitimacy of local knowledge due to deeply rooted belief systems and values, which led to a fragmented process and knowledge outputs that were not applied to decision-making. The Dutch water management projects illustrate how integration and homogenization of knowledge might be effective in generating a 'result,' but such efforts are rendered futile when the output, and thus outcomes, is subjected to those same system dynamics and biases post-process. Their lack of outcomes underscores the importance of the process as being pivotal to co-production, rather than solely focusing on 'content'. Each of the stakeholders had different norms and criteria for knowledge production that reflected their diverse worldviews, assumptions, and interpretations. Identification of the epistemic context and everyday knowledge processes of participants is

warranted due to different perceptions of credibility and legitimacy (Muñoz-Erickson et al., 2017).

Power relations are often reflected in the validation or prioritization of one knowledge type over another (Davidson-Hunt & O'Flaherty, 2007). Knowledge can be easily commandeered when a single scientific discipline or social actor involved in co-production gives validity to their own perspective only (Pohl et al., 2010). Climate change and other environmental problems are continually being framed as global issues that warrant broad, objective solutions informed by scientific-rational knowledge, which supersedes local or traditional knowledge. These same ideals can and have been carried over to co-production. Values legitimize scientific knowledge by making it the standard upon which local knowledge is measured. In attempts to legitimize local knowledge, researchers are only validating scientific knowledge, values, and worldviews.

Knowledge claims over resources are an additional exercise of power, where one set of participants assert their own truth claims that then form the basis of decision-making (Davidson-Hunt & O'Flaherty, 2007). For example, the Tunari National Park co-production project was initiated due to the central government's proposed conservation plan for the environmental resources within the park that would limit their access to indigenous Quechua communities living within the park. Whereas the farmers asserted their rights to the resources, government officials sought

to preserve ecosystem functions, conserve water supplies and biodiversity, prevent floods, and maintain recreation and tourism. Their scientific-conservationist knowledge claims would impose stringent limitations to agriculture, livestock, and agroforestry.

The co-production literature often cites the need for trusting relationships among participants but establishing this trust can be difficult in settings of historical mistrust due to power imbalances and scientific skepticism. To communities, researchers embody the 'other,' both in knowledge and intent, which can pose complicated barriers to overcome in establishing collegial partnerships (Castellanos et al., 2012; Moller et al., 2009; Pearce et al., 2009; Pohl et al., 2010; Shaffer, 2014). The same standards and transactional relationships found throughout science are often applied to participatory research efforts with communities, which creates resistance among communities as it closely resembles the controlling, colonialist logics and practices of the not-so-distant past. There is a deeply rooted culture of mistrust of Western science among communities whose livelihoods or traditions depend on natural resources (Pearce et al., 2009). Indigenous peoples are often skeptical of research collaborations due to historically prescriptive management practices that impose limitations or prioritize maximizing economic yields (Adams et al., 2014). For example, upon initiation of the project with the Maori birding community, individuals expressed resentment and concern due to the perception of a critical divide between science and Māori culture (Moller et

al., 2009). One resident voiced their fear that global framings of environmental research and international participation would raise the risk of losing control over their knowledge. In a co-production project between farmers, government agencies, and soil scientists in Switzerland, farmers revealed their skepticism of rules and norms derived from science, as they distinguish those as “coming ‘from above’” (Pohl et al., 2010, p. 274). In the Mlingotini community of Tanzania, local fishers, suspicious towards the government and harvesting regulations, prevented local co-researchers from monitoring fish production despite explanations and guarantees of anonymity (Shaffer, 2014). Shaffer attributed these research difficulties in Mlingotini to problems with trust and communication.

Knowledge Opportunities

Constructing knowledge systems that reflect the local context will warrant more inclusive and pluralistic conceptions and approaches for defining and understanding knowledge, as well as the individuals who produce and use them (Muñoz-Erickson et al., 2017). Understanding knowledge as a process, rather than content is an appropriate starting point for bringing fundamentally different knowledge systems together and addressing power imbalances. The process of knowledge and the social systems in which it is embedded are dynamic and co-produced methodologies must evoke the mechanisms by which knowledge is produced, including its formation, validation, and adaptation in the face of

change (Berkes et al., 2000; Davidson-Hunt & O'Flaherty, 2007). Parallel approaches to creating synergies between knowledge systems underscores their complementarities and ability to enrich one another while still maintaining independence (Berkes et al., 2006; Tengö et al., 2017). Moller et al. (2009, p. 224) highlights that the project with the Maori never espoused "submerging differences, or seeking some blend or mix of knowledge systems that pretends these are not very different ways of knowing." The opportunities for co-production to generate synergies among knowledge systems and actors are numerous, building mutual processes of trust, learning, and creation for cross-cultural co-research and co-management (Davidson-Hunt & O'Flaherty, 2007; Moller et al., 2009; Tengö et al., 2014). According to Maclean and Cullen (2009, p. 206), "research must strengthen indigenous knowledge, rather than simply utilise existing traditional knowledge."

Pohl et al. (2010) suggests that the first step to identifying the knowledge systems present in the co-production process is to jointly define the goals and scopes of the analysis, which reveals what they refer to as 'thought collectives' (Fleck, 1979). Each member of a social group shares a thought style that aids them in processing the relevant aspects of issues, how to explain them and how they should be approached. A thought collective is a carrier of a thought style, and within the collective, communication is effortless, whereas members from different thought collectives, or social groups, might encounter difficulty understanding one

another (Fleck, 1979; Pohl et al., 2010). Thought collectives are similar to the different reference frameworks Kraaijvanger and Veldkamp (2017) attributed to Ethiopian farmers and scientists participating in the joint agricultural experiment. Their different backgrounds and contexts in which they operate reflected the divergent decisions they made, all of which when understood helped shed light on the pathways for learning and meaningful collaboration.

The case studies used a variety of practices to better engage the knowledge systems and facilitate active learning. Akpo et al. (2015) engaged in participant observation, learning activities, and interviews to understand the different ways stakeholders cooperated and communicated with each other, as well as the framings and terms used to conceptualize and act on the various palm oil nursery practices. Participation in ceremonies and other cultural activities gave some scientists insight into the processes behind the transgenerational transfer of traditional knowledge (Cullen-Unsworth et al., 2012; Davidson-Hunt & O'Flaherty, 2007; Moller et al., 2009). Workshops and group discussions were another useful method to support collaboration in designing and carrying out the projects for many of the case studies (Castellanos et al., 2012; Davidson-Hunt & O'Flaherty, 2007; Kraaijvanger & Veldkamp, 2017; Pohl et al., 2010). Community meetings similarly encouraged participation, open discussion, and the sharing of knowledge and experiences (Cullen-Unsworth et al., 2012; Moller et al., 2009; Shaffer, 2014). Some more

specific techniques include participatory mapping exercises (Gutberlet, 2015; Pearce et al., 2009; Raymond et al., 2010; Wolfe et al., 2007), diagramming techniques (Castellanos et al., 2012; Gutberlet, 2015), collectively generating lists (Shaffer, 2014), and collecting experiences through film (Gutberlet, 2015; Pohl et al., 2010).

Trust and respect for participants, and their knowledge systems, are prerequisites for collaboration and an outgrowth of empowerment. Establishing trust and close relationships were identified by the case studies as essential to community-research collaborations and the progression of the projects (Cullen-Unsworth et al., 2012; Davidson-Hunt & O'Flaherty, 2007; Moller et al., 2009; Pearce et al., 2009). For example, Wolfe et al. (2007, p. 85) explains that co-production is most effective in settings "where trust-building has been a precondition of project implementation, and where the different groups engaged in interdisciplinary research share a mutual respect for diverse perspectives." For many of the case studies, informal interactions helped build trust and rapport and motivated participation (Castellanos et al., 2012; Cullen-Unsworth et al., 2012; Gutberlet, 2015; Moller et al., 2009; Pearce et al., 2009). In the Arctic case studies by Pearce et al. (2009), the scientists gained rapport by spending time participating in community activities and lodging with local households during research visits. Another way trust was built involved co-researchers spending time together on the traditional lands of the case studies' indigenous communities (Cullen-Unsworth et al.,

2012; Moller et al., 2009; Pearce et al., 2009). These personal and integrative interactions help establish cross-cultural understanding, which Cullen-Unsworth et al. (2012) identified as crucial for the progression of research and successful outcomes. Gutberlet (2015) reported her methods for establishing an open and trusting environment, which included workshops with various icebreakers, such as psychodrama, acting, light physical exercise, and generally encouraging the sharing feelings and ideas to other participants.

Transferring ownership and control of a project to the community is one way of ensuring respectful, mutual relationships while helping to redistribute power over knowledge. Questions regarding the protection of intellectual property, ethical data collection, and resource rights present the opportunity for local ownership of the process and outcomes in co-production (Latulippe & Klenk, 2020). For example, the Rakiura Māori communities of New Zealand were most apprehensive towards the birding project, fearing external control of birding and racist interference (Moller et al., 2009). The authors report that transferring control of responsibility and research processes to the Rakiura Māori was essential for the community to feel safe. This included the project's goals, methods, ethics, interpretation, and dissemination strategies. A community research director explained the reasoning for this decision: "We needed to have control of it [the science project]. We wanted to be steering the boat rather than being part of the crew in the way we usually are" (Moller et al., 2009,

p. 228). Participatory experiments feature the community collecting the data and generating knowledge in collaboration with science, which encourages them to own the new knowledge (Akpo et al., 2015; Kraaijvanger & Veldkamp, 2017; Shaffer, 2014). For example, environmental monitoring in Tanzania was done by community representatives who recorded their observations using tools supplied by participating scientists, and they reported their results to the community directly (Shaffer, 2014). The broader community understood where the data came from and by whom, which enabled them to focus on discussions of how mitigate the environmental effects being observed.

Framing a co-production project internal to the local knowledge system presents the opportunity to reshift the power dynamics involved in validating knowledge systems. Cullen-Unsworth et al. (2012) restructured the Wet Tropics World Heritage Area (WTWHA) project away from the primacy of scientific measurements and indexes by transferring the project framing internally to the Aboriginal culture. The project aim was to create linked biophysical and cultural indicators for the WTWHA. The linkages came from the cultural values internal to the traditional ecological knowledge of the Aboriginal communities, and connected to the tangible biophysical environment that was also based on their ecological knowledge. The cultural values were not linked to scientifically derived biophysical indicators. The aboriginal participants were apprehensive of linking their cultural knowledge to scientifically-derived indicators due to

worries about cultural appropriation and extractivist scientific practices. Keeping the indicators rooted in local knowledge and perceptions of biophysical change enabled their combination with the documentation by scientists and their perceptions of biophysical change.

Jointly defining the output of results presents another opportunity for ensuring the accessibility and accurate representation of knowledge so that no one source is dictating the knowledge post-process. Many of the case studies found creative ways to disseminate the project results to community co-researchers in addition to their own established methods of dissemination through publications. In addition, most of them used multiple forms of delivery. For example, Gutberlet (2015) translated research results into accessible formats, such as booklets, newspaper articles, posters, and videos, which were sent to recyclers, government agencies, and the broader community. To incite community dialogue, the research team on the birding project developed a community newsletter, called the Tītī Times, which showcased research results, other information of interest, such as birding history, and key community birders and family members (Moller et al., 2009). Despite taking extra resources, the newsletter was enthusiastically received and now attributed to restoring intra-community relationships. Castellanos et al. (2012) distilled their team's research results into a report for policymakers, a puppet play for the public, and a calendar for the communities with important messages for each month. In addition, they identified radio as a popular means of

communication in rural areas, and condensed the results into useful public service announcements for the farmers. Several case studies reported community meetings or workshops to present research findings and get community feedback (Akpo et al., 2015; Castellanos et al., 2012; Cullen-Unsworth et al., 2012; Davidson-Hunt & O'Flaherty, 2007; Moller et al., 2009; Raymond et al., 2010; Shaffer, 2014; Wolfe et al., 2007). To ensure the results are an accurate and appropriate representation of traditional knowledge, review and approval of any findings must be sought prior to publication. The negotiations involved in reaching an agreement about the forms of output facilitate ensuring the results will be accessible to each of the co-researchers. Discussions about the expected content and formats of the results should be done in the beginning of a project to maximize transparency.

Reflexive evaluation throughout the process is a way to ensure the project is meeting its original goals and no one participant group is taking control of the knowledge flows. Castellanos et al. (2012) used small group activities, including validation workshops and group discussions, to regularly confirm their findings. Ongoing reflection on the research practices will assist project facilitators in identifying what is and is not working for the group's learning. For example, at each project meeting, scientists facilitating the experiment among stakeholder groups in the oil palm seed system revisited the previous meeting to discuss whether the experimental treatments had changed, which prompted iterative analysis,

evaluations, and discussions (Akpo et al., 2015). In working with the Iskatewizaagegan No. 39 Independent First Nation (IIFN) to document forest values, Davidson-Hunt and O'Flaherty (2007) hosted community meetings to update the projects progress and seek feedback from the local elders. These meetings helped scientists to interpret their findings and recognize pathways forward in the research. Recording meeting minutes was a common method in the projects to not only document the process, but to summarize the interactions and communicate them back to the other participants for approval.

In conclusion, knowledge can be highly contested when working with communities, but finding synergies can improve co-production relationships, mobilization, and outputs. Ways of doing so include:

- Recognizing knowledge as a dynamic process and tailoring co-production to reflect that fact can help prevent practitioners from seeking to cherry-pick certain pieces for utilitarian purposes.
- Methods for engaging the plurality of knowledge systems include: participant observation, learning activities, interviews, workshops and group discussions, mapping and listing exercises, and diagramming techniques.
- Ways of building trust include: informal interactions, engaging in community activities, and icebreakers

(psychodrama, acting, light physical exercise, sharing emotions).

- Transferring ownership and framing of the project to the community helps ensure a respectful, safe process that engenders transparency and accountability.
- Co-production outputs should be made accessible upon the delivery stage, both in quantity and type, such as newsletters, videos/films, radio broadcasts, calendars, community presentations, and booklets.
- Ongoing reflection and evaluation helps affirm the results and maintain the project's original scope and objectives. Validation workshops and meeting minutes are two ways of upholding reflexivity.

Conclusions

This research examined whether and how communities and local knowledge are being embedded in the process of knowledge co-production for environmental outcomes. In synthesizing the literature and community-focused case studies, my objective was to shed light on the current practical applications of co-production and the different manifestations of power, barriers to inclusion, and the dimensions of institutional capacities that might preclude community involvement, thus determining *whether* they are integrated in the process. In addition, my aim was to identify more specific practices that might guide practitioners in *how* to include communities given existing challenges. I did so by reviewing the broader co-production literature, over 200 scholarly articles, books, and manuscripts, and followed with a more detailed, inductive analysis of 13 articles with 20 case studies. There are multiple ways of organizing this complex and overlapping literature. In the review above, I sought to convey the information in a way that might be most useful for practitioners to identify the failures commonly reported in the case studies and literature.

After an introduction, I provided an overview of the methods used in the literature review. I then clarified the meaning of local knowledge and the benefits to community involvement for both them and co-production as a whole. I subsequently provided a background of co-production including its theoretical underpinnings and praxis, which reveals a complex domain

of applications, logics, lenses, and approaches. The results investigated 20 case studies to identify the constraints associated with the current barriers of capacities, and power and inclusion that inhibit the engagement and participation of local actors. The following sections described the opportunities in terms of the various precautionary measures, social configurations, and stimuli that foster environments for co-production and the subsequent uptake of knowledge with community stakeholders.

Despite challenges, co-production as a concept and practice shows a great deal of promise. Co-production is an established domain of research and practice and it has generated significant insights. Co-production draws its roots from three different scholarly fields and has come to define its own methods and theories to challenge how research is conducted. The constructivist application of the co-production concept provides analytical insight into the relationships between knowledge (including science, TEK, and other systems), nature, and governance. In deconstructing the relations and actions involved in generating knowledge and governance, co-production provides a window into how they can be reshaped, or transformed, to better further sustainability. For co-production, the barriers to normative co-production, like any other knowledge making practice, provide input to be analyzed by its descriptive counterpart, which can generate a feedback loop of mutual advancement. Ultimately co-production is in a unique position to develop into its own research tradition.

Co-production underscores the need for participation from all stakeholders for co-creating both the knowledge and the social dynamics to act on it, thus transforming decisions and governing arrangements (Miller & Wyborn, 2018, p. 5). Co-production endeavors to democratize science and governance to enable citizens to take part in defining, creating, and enacting knowledge that helps establish a world in which they want to live. The emphasis on all stakeholders sets an important mandate for its engagement approaches, such as participatory integrated assessment, otherwise they are able to revert back to contractual modes of engagement. Maintaining underlying principles and conditions helps differentiate co-production from other participatory practices while setting precedents for its future practice.

A critical challenge facing co-production is the reification of exclusionary mechanisms that co-production set out to oppose in the first place. Researchers and decision-makers exercise the power to determine who participates and what types of knowledge are included. Co-production asserts the goal of inducing ‘transformation’ for sustainability outcomes, yet little transformation is occurring if co-production is subject to political agendas while scientists maintain explicit or implicit control over the project’s scope, methods, and knowledge validation. Instead of co-producing new forms of distributive governance, co-production can reinforce the elite stronghold over knowledge and environmental resources. First and foremost, co-production must ask whether those who

have been invited are the appropriate representatives. In many cases communities have the procedural right to be there, but power dynamics might keep them away.

Another decisive challenge in which co-production practitioners must grapple is the mechanisms that repress community participation while in the process. The idea that participatory engagement is a requisite for effective knowledge production, transfer, and implementation forms a central tenet behind the concept of co-production. Co-production endeavors to defy traditional scientific models of research by including every stakeholder related to the given problem and democratizing the process for equality. Despite this, community participation is often relegated to selective consultation at some point to fulfill certain predetermined objectives. Unequal participation was reflected and widespread in my initial search for co-production case studies. Out of 31 articles that featured communities in some capacity, only 13 of them maintained community involvement from beginning to end, and by 'community' emphasized laypersons (i.e. farmers, hunters, fishermen, etc.). Besides openly limiting participation within the process, additional restrictive practices include: ignoring socio-political contexts and power dynamics to quickly generate usable knowledge tools; distilling local knowledge to supplement scientific knowledge; using scientific knowledge as a means of validating local knowledge; maintaining insulated, depoliticized spaces that fail to challenge existing institutions; and

removing traditional, place-based knowledge from its local socio-ecological context for the sake of global narratives. In addition, the current, rigid funding requirements, incentive systems, and lack of boundary spanning training further confine the capacity for co-production to take place at the community level.

In light of these challenges, I highlight cases that demonstrate co-production with communities, which can serve as models for guiding future efforts. These methods are not universal, and co-production itself is not a silver bullet, but they do provide a good starting point for a more integrated, community-based research experience. This thesis aimed to distill some of the practices and considerations to inform a co-production project working with communities as one of the key environmental stakeholders. The main contribution of this thesis has been to look at how co-production engages with local environmental knowledge, whether in communities or groups of stakeholders. To do so, I synthesized and discussed what is being done on the ground in the context of some of the challenges that have precluded or complicated community engagement. The results provide practical steps for guiding researchers and enhancing the process and products of co-producing environmental knowledge for sustainable outcomes. Some key findings include:

Constraints

1. Conventional, fixed scientific and funding timelines lack the flexibility to accommodate the social commitments and cultural

obligations commonplace to community life, which could limit interactions with communities and other stakeholders.

2. Elites, such as those from governments, NGOs, and research institutions, have the disproportionate ability to shape the co-production process, and some instrumental logics driving co-production practices end up strengthening these inequalities.
3. Tense, closed spaces and resource disparities can affect the perceived accessibility to the participatory process and other actors.
4. It is difficult to ensure all relevant stakeholders are included in the process.
5. Many co-production approaches and much of the literature espouse "integrating" in the sense of assimilating one knowledge system, usually that of IPLCs, into another.
6. Knowledge claims over resources are another manifestation of power.
7. There is a culture of mistrust of western science among communities whose livelihoods or traditions depend on natural resources.

Opportunities

1. Using multiple methods of stakeholder identification, such as open community meetings or pre-existing social networks, is one way of reducing the risk of exclusion

2. Participation and representation should be decided from the community itself, not outsiders.
3. Workshops and learning activities, group discussions and community meetings, participant observation, and interviews are ways to engage the different knowledge systems and facilitate active learning.
4. Informal interactions, participating in community activities and local traditions, and workshops with various icebreakers, such as psychodrama, acting, and light physical exercise were identified as ways of establishing relationships and building trust.
5. Transferring ownership, control, and the framing of a project to the community are some ways of alleviating fears of knowledge co-option while increasing the transparency and ownership of the project.
6. Using local vernacular, drawings, and accessible research outputs, such as community newsletters, radio announcements, community presentations, films, improve communication and accessibility of the process and results.

Despite some of the challenges pervading co-production, there is a path forward to strengthen the research process, and I argue it begins by being more deliberative about the inclusion of communities and local environmental knowledge. Co-production practitioners need to consider communities as more than resources to meet some end, as they can

enhance the practice of co-production beyond a utilitarian sense. Co-production projects should be vesting power in local communities, and not just in community elites, such as policymakers. Even maintaining 'producers' and 'users' of knowledge implies the users are not contributing knowledge which sustains the division between participants and maintains the 'other.'

Moving forward, co-production should not be equated with fast research approaches, quick results, and extractive or assimilative methodologies that have become commonplace with newer instrumental logics. Understanding co-production as a process draws a parallel to knowledge as a process. It is not simply pre-set methodologies that are universal in every situation, rather the process should be adapted to the local context and maintain reflexivity and flexibility to embrace the complexity inherent to socio-ecological systems. In doing so, co-production replicates the knowledge system, whereby knowledge is created, validated, adapted, and transmitted, thus enabling co-researchers (all stakeholders) to co-produce salient, local knowledge (Berkes et al., 2000; Davidson-Hunt & O'Flaherty, 2007). Taking a step further, co-production that is framed internally to the local knowledge systems helps to ensure an appropriate process that maximizes transparency and the ownership and application of its results (Cullen-Unsworth et al., 2012).

Co-production would also benefit from some conceptual uniformity; the current labyrinth of analytical and practical applications allows one to

pick and choose what parts of co-production will parsimoniously achieve some predetermined outcomes, thereby changing the degree of engagement according to the end product. The literature takes aspiring practitioners into many different directions and muddles the underlying principles and goals of its praxis. For example, if the intended outcome of co-production is empowerment, then the process deliberately builds means of empowerment throughout its stages. Conversely, if the intended outcome is usable science then the implication is that empowerment is not a priority, therefore marginalized communities might not be represented in the process or outcomes as they need empowerment to participate fully.

Co-production is not a panacea for all environmental research, and there are a number of caveats concerning its application. There are cases when co-production would not be an appropriate or applicable process to undergo. Namely, if the barriers identified above are insurmountable and the quality and substance of the process would suffer as a result. If practitioners are forced to regress to contractual and consultative modes of engagement with communities then I would argue that co-production is not suitable since its underlying principles could not be met. Instead, alternative collaborative methods should be pursued.

With that said, I would also argue that co-production is a better way of conducting environmental research and management. The complexity of today's environmental and societal problems warrant more inclusive definitions and solutions. We must deconstruct our perceptions of

expertise and democratize knowledge production for more holistic understandings of the systems around us. Communities have not secured an explicit focus for co-production, but they provide the scale at which our efforts must be redirected.

Finally, more research is needed on the challenges and opportunities discussed in this thesis. For example, it would be advantageous to identify co-production indicators related specifically to diversifying participation and ensuring equal representation. More interdisciplinary discussions and collaborations focused on local environmental knowledge and stakeholders are needed to propel co-production forward. Although research is increasingly focused on the barriers to co-production, this thesis shows they are best studied in the context of community involvement. We need to keep power and politics in our focus, regardless of how uncomfortable and challenging it may be. They affect representation, yet the principles, methods and experience of co-production is well positioned to take on this challenge and sustain it. More long-term and diverse sources of funding should be explored and evaluated to encourage co-production and enhance its capacity.

As I finish writing this thesis, much of the world is in quarantine due to the COVID-19 viral disease. Since global, and in some cases national, efforts have remained largely ineffective, the virus has tested our resilience as communities and our capacity to work together towards a shared goal. It has been the nurses, doctors, grocery clerks, cooks, and

postal workers, among many others, who have proved essential in this time of desperation and fragility. Their practice has quietly co-produced a significant part of our knowledge and practices about this virus. This knowledge and practice needs much more recognition, integration and political power at all levels of governance. As environmental problems continue to manifest, it is imperative that we continue to build our co-productive capacity, and maybe COVID-19 can be an instructive and impactful impetus for doing so.

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Appendix

Table 1

Codes used in the stages of text analysis

Stage of literature analysis	Code	Application
Initial identification of co-production applications; and initial coding of case studies	“Co-production definition and characteristics”	Any segment of text that defined co-production or described its underlying tenets
	“Type of co-production”	Text that described an approach or methodology for co-production
	“History”	Text that recounted the theoretical and practical origins for co-production
	“Application”	Text that described the context in which co-production took place
	“Problem/rationale”	Text that identified the reasoning for co-production, including current limitations in research
	“Outcome/finding”	Text that summarized the main findings of the paper and any outcomes of the project
	“Purpose/methods”	Text that identified the paper's gap
	“Challenges”	Text that considered the obstacles to co-production work
	“Guideline”	Text that identified lessons learned and considerations necessary for co-production projects
Second coding of case studies	"Context"	Any segment of text that discussed the social, political, economic, and ecological conditions that would have some bearing on the project.
	"Co-design"	Text that described specific methodologies and factors related to the project’s inception, problem framing, stakeholder identification, and other activities associated with the initial stage of co-production
	"Mobilization"	Text that identified any activities and methodologies that related to working and learning together after the project's design
	"Delivery"	Text that described packaging and dissemination of the project's results, as well as any outcomes
Third coding of case studies	"Capacities"	Any segment of text that described the contextual factors that influenced (or potentially) the project, including limitations and solutions
	"Power and inclusion"	Text that identified factors and activities/methodologies related to power dynamics and the participation of community stakeholders
	"Integration" (subsequently merged with power and inclusion)	Text that described limitations and activities/methodologies (solutions) to bringing different knowledges together in co-learning