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Science-Policy-Practice Interfaces: Emergent knowledge and monarch butterfly conservation

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ABSTRACT
We study how knowledge is produced at the intersection of science, environmental policy and public engagement. Based on analysis of monarch butterfly conservation, we critically evaluate models of knowledge production. The monarch butterfly and its migration have engaged science and enchanted people for over a century, and current threats to monarchs catalyze debates and actions. This paper traces the historical development of knowledge regarding (i) long-term monarch population trends, (ii) the monarch's dependence on a particular food plant, the milk-weed, and (iii) the monarch as a pollinator. Our analysis indicates that knowledge production and science–policy–practice interfaces cannot be satisfactorily understood through reference to the classical linear model and more recent conceptions of relationally produced knowledge (i.e. co-production). We identify powerful and sometimes contradictory knowledge claims that emerge from unmediated interactions among scientists, advocates, policy makers and diverse publics. The emergent model complements existing models of knowledge production, thereby expanding the conceptual foundation available for making sense of science–policy–practice interfaces.

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Introduction

To CREATE A SUSTAINABLE FUTURE WE MUST UNDERSTAND HOW ENVIRONMENTAL PROBLEMS AND SOCIAL RESPONSES ARE constructed. More specifically, we need to know how knowledge about the environment is produced, circulated and legitimated, and how different modes of knowledge production contribute to social and environmental change. Scientific knowledge is often identified as a direct input into decision making. In this classical conception, the connection between science and socioeconomic change is linear and unidirectional (Yearley, 2005). However, the idea of a linear process in which scientific output results in policy decisions and shifts in public understanding has long been criticized as an abstraction that poorly describes processes of social change (Funtowicz and Ravetz, 1993; Nowotny *et al.*, 2001; Yearley, 2005).

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In the past 30 years or so, an interactive, relational conception of knowledge production and social change has emerged. This multi-polar model highlights tensions and complementarities among scientists and variously situated local actors (i.e. practitioners, engaged citizens) (Rosenberg, 1982; Yearley, 2005). Applied to policy decisions, the stakes, uncertainties and fundamental importance of the particular values of individuals and social groups that characterize contemporary debates about the environment present a situation in which knowledge production should, it is argued, increasingly be understood and advanced through dialog among differently situated actors (Funtowicz and Ravetz, 1993; Hajer and Wagenaar, 2003). Acknowledgement of different knowledge practices and the importance of 'co-production' of knowledge represent an explicitly relational conception of and prescription for science, policy and development (Jasanoff, 2004; Palmer, 2012; Weber and Khademla, 2008). This commitment to interaction stands in contrast to the under-socialized, decontextualized conception of knowledge production at the heart of the linear model.

Contemporary treatment of science–policy–practice interfaces recognizes linear and relational aspects of knowledge production as useful heuristics (e.g. van Kerkhoff and Lebel, 2006). In problematizing these models as ideal types and specifying their shortcomings, empirical studies highlight interdependence of linear and relational processes, as well as the significance of context and interests in shaping expressions of knowledge. For example, Cash *et al.* (2003) emphasize how credibility, relevance and legitimacy of knowledge in particular circumstances mediate how scientific knowledge comes to be employed for problem solving in policy domains. Sarkki *et al.* (2017) highlight how pragmatism – i.e. the privileging of knowledge claims that align with established problem definitions – crowds out the introduction of new knowledge in policy processes. Dunlap and McCright (2011) identify organizational networks committed to shaping public policy and public discourse through strategic programs of misinformation.

As part of ongoing efforts to make sense of dynamics in science–policy–practice interfaces, we highlight a degree of unpredictability attached to contemporary knowledge generation, a process that we term 'emergent'. Interactions among scientists, activists, policy makers and citizens can produce surprising and powerful knowledge claims when problems are widely debated and relevant in a wide range of contexts. In the language of systems theory, knowledge dynamics have emergent properties that could not be anticipated from an understanding of the lower level sub-systems (i.e. individual scientific claims, engaged citizenry, policy debate and popular culture) (Allen and Starr, 1982). Academic analysis of policy processes has long recognized indeterminacy (e.g. Baumgartner and Jones, 1993). Policy studies have highlighted a degree of randomness attached to which knowledge – from the available stock – emerges as relevant in a given problem solving context (Kingdon, 2003). Here, we focus on randomness attached to construction of knowledge. In other words, beyond the question of which of the available knowledges will gain traction and be put into practice, we highlight the dynamic nature of knowledge generation in policy processes. When the bright lights attached to popular and policy debate shine, this energy introduces new demands and opportunities that can give rise to effective, if sometimes bizarre, knowledge claims.

Through study of the monarch butterfly and a layering of the three ideal type models sketched above – linear, relational and emergent – this paper aims to explain how knowledge is produced at the intersection of science, advocacy, environmental management and public engagement. We analyze knowledge claims that structure the monarch conservation debate in order to assess the value of introducing an emergent model of knowledge production. Our analysis focuses on three questions at the core of current debates about the ecology and conservation of the monarch butterfly: (i) What are the long-term monarch population trends? (ii) What is the relationship between decline in milkweed and the monarch population? (iii) What are the conservation implications of categorizing the monarch butterfly as a valuable plant pollinator? This exercise provides insights into monarch butterfly conservation, and it serves to expand the conceptual foundations available for making sense of production, circulation and application of knowledge.

Analytical Perspectives on Knowledge Production and Circulation

Linear and Relational Conceptions of Knowledge Production and Social Change

The core claim of the linear conception of knowledge production is that scientific output results in social change by adding relevant knowledge to the existing stock and by excluding false claims. This cumulative process of knowledge

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production process yields facts and capabilities that have an objective and global character. These outputs are context independent 'immutable mobiles', entities that can be transferred between different social and geographical settings without losing or changing their meaning (Latour, 1986). As an ideal type, the linear model positions scientists as separate from society. They are trustworthy, capable and responsible for producing knowledge that leads society forward (Nowotny *et al.*, 2001). Citizens and policy makers are understood as ignorant until informed (Lewenstein, 1992; Yearley, 2005).

The relational model of knowledge production, as an ideal type, emerged as a critique of the linear model. The model argues that actors outside of science possess vital knowledge and play prominent roles in knowledge production (Irwin, 1995; Yearley, 2005). The experiences of practitioners are understood as being incorporated into knowledge on an ongoing basis (Rosenberg, 1982). The field highlights social dimensions of scientific practice, and scientific knowledge is understood as a product of negotiations, interaction and learning among diverse actors (Collins and Pinch, 1993; Guston, 2004). Within the field of STS, these ideas are referenced through the ideas of 'mutual shaping' or 'co-production' (Jasanoff, 2004).

Toward an Emergent Conception of Knowledge Production and Social Change

The linear and the relational models differ on many points, especially in terms of where agency is located and where knowledge claims derive authority. Both, however, assert the central role of validation of knowledge claims within processes of policy decision making and social change. Peer review serves as the arbiter of validity within the linear model (Cole *et al.*, 1981), and deliberation is the analog within the relational model (Habermas, 1984). At present, science policy and academic engagement with science–policy–practice interfaces are anchored around these two models of ideal types. Science retains its status as an engine of progress, and co-production is increasingly institutionalized as an organizational principle of 'good governance' and sustainable transitions (Palmer, 2012).

While the linear and relational models are often set in opposition to one another, we observe substantial experimentation geared around combination and integration. We observe expanded roles for advisory boards in shaping research programs and funding priorities as part of efforts to make science more transparent and responsive. Contemporary emphasis on public, engaged and transdisciplinary scholarship has the potential to build on participatory research traditions to empower non-scientists in efforts to mobilize academic resources in response to social problems (Gaventa, 1988). With respect to how science is articulated within policy processes, as Guston (2004) suggests, we observe interest in communities of practice, science shops and expanded public scientific literacy as means to allow non-scientists to participate in policy deliberations on subjects typically dominated by technical elites (see, e.g., Iyalomhe *et al.*, 2013; Paloniemi *et al.*, 2015; Stirling, 2010). These examples highlight efforts to draw on the power of experts while simultaneously engaging critically with their positions of authority.

Layering the linear and relational models onto one another and placing them in tension with each other is attractive, but it does not provide a comprehensive account of the origins of all knowledge in circulation. We identify processes of knowledge production leading to social change that bear little correspondence to these ideal types and to existing critiques of these established models. Specifically, we observe actionable knowledge claims emerging unpredictably, unmediated by traditional assessments of validity.

As we represent the process here, knowledge production sometimes takes on 'a life of its own'. Some symbols and arguments gather momentum and attain status in popular imaginations, media, commerce, politics, professional practice and science (Allaire and Wolf, 2004). Case studies focusing on related phenomena and the process have been carried out in multiple empirical fields: see, e.g., the importance of nonhuman charisma when promoting flagship species (Gustafsson *et al.*, 2015), refutation of evolution (Ehrenreich and McIntosh, 1997) and climate skepticism (Dunlap and McCright, 2011). However, the processes that enable knowledge claims to 'go viral', and the determinants of which memes gain wide circulation and are retained over time, are not fully understood.

Although the mechanisms are unclear, we identify knowledge production and social change that corresponds to neither a linear nor a relational process. Instead, the process can be understood through reference to surprise and emergence through networks. As ideas and symbols gain traction, and they engage mass audiences increasingly distant from the origin, shifts in content and meaning occur and new knowledge is created (Allaire and Wolf, 2004). While this mode of knowledge production implies a decay function and loss of fidelity as ideas travel across boundaries, we also must emphasize how diverse actors project their particular conventions and interests onto knowledge claims in

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processes of interpreting and applying knowledge. Both processes – decay and projection – can produce mutations in existing knowledge. As a function of knowledge claims entering mainstream circulation and engaging ever-larger numbers of actors and diverse settings, knowledge is increasingly plural.

As Innes (2004) has forcefully argued, applied to consensus building for policy planning 'in situations where controversies and multiple goals and contradictions abound' (p. 6) and historical relations of power shape interactions, 'the discussion does not proceed through the force of the better argument' (p. 7) as is suggested in the highly influential theory of communicative rationality advanced by Habermas (1984). 'The idea of communicative rationality is an epistemological view, parallel to the idea of scientific method. In this model, where interests engage in dialogue, undistorted by power differentials and information differences and where assumptions are challenged, a kind of truth is formed. Shared understanding develops, reifications are broken down and interests work through their differences to produce more complete, meaningful, and robust knowledge than scientific method or socially-constructed negotiations' (Innes, 2004, p. 7).

Applied to our argument, communicative rationality maps very closely onto the relational model of knowledge production. In parallel with Innes, we argue that the 'truth' that emerges from social interactions around ambiguous and contentious issues among sets of actors that engage from very different cultures, interests and knowledges should be understood as distinct from rationality as expressed in science and in mediated processes of co-production.

In stressing the non-linear and unpredictable nature of knowledge production and social action, the 'garbage can model' of organizational decision making (Cohen *et al.*, 1972) and policy processes is relevant. Kingdon (2003) highlighted the chaotic character of policy decision making, and he recognized the shortcomings of a linear, comprehensively rational model of which problems and interventions emerge from the metaphorical garbage can at a given time. In his attempt to make sense of unpredictability in the outputs of policy processes, he emphasized interactions among (i) a set of material problems, (ii) a set of potential policy solutions and (iii) political windows of opportunity. The model calls attention to randomness regarding which problems are addressed and which types of available knowledge are called upon to mount responses. The emergent model we introduce here also highlights unpredictability in the knowledge that becomes relevant in policy processes, but the randomness we focus on is attached to the processes that enable knowledge claims to combine, morph and become established. Kingdon's metaphor is a garbage can that contains a variety of stable knowledge claims, each of which can be mobilized if called upon. Our metaphor is a cauldron within which knowledge mixes, taking on new forms and gaining new powers to advance social change.

As an ideal type, our emergent model of knowledge creation emphasizes the absence of a central moderator or facilitator. The actors and interfaces are unspecified, and claim making applied to knowledge is weakly mediated. When information and references enter into popular culture and public consciousness, the knowledge claims that surface – and that come to serve as justifications for actions – do not conform with the evidentiary and deliberative processes we associate with the linear and relational models. Knowledge that emerges from chaotic and unscripted interactions among scientists, aficionados, entrepreneurs, activists, public officials and mass culture is sometimes weakly supported by evidence. The validation processes that define the linear and the relational models are not features of the emergent model. When challenged on the potentially problematic relationship between quality (i.e. validity) of information represented in internet memes and the number of people accessing these memes, a journalist's account of a leading internet meme entrepreneur is telling.

> Spartz experiences no tension (between quality control and expanded digital capabilities), because he does not distinguish between quality and virality. He uses 'effective,' 'successful,' and 'good' interchangeably. At one point, he told me, 'The way we view the world, the ultimate barometer of quality is: if it gets shared, it's quality' (Marantz, 2015).

In recognizing that evidence and deliberation are not the basis of all knowledge claims in circulation, and that the commitments to rigor of science and the socially mediated outputs of co-production do not comprehensively explain what passes for knowledge in public and policy debate, we confront an important phenomenon. Engagement of mass publics presents opportunities for erosion of commitments to evidence and to accountability applied to knowledge claims. In the contemporary context in which public engagement with nature, science and policy is

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articulated as a key element of a transition to a sustainable future (see, e.g., Palmer, 2012), we see a need to highlight emergent processes in knowledge production.

Analytical Approach and Empirics

Our analysis of the case of the monarch butterfly is based on grounded theory, an inductive approach to advancing conceptual arguments based on a structured investigation (Bryant and Charmaz, 2007). In order to identify knowledge claims that structure understanding of monarch conservation, we analyzed scientific, advocacy and policy document dialogue on listserves and the content of monarch science and conservation conferences. To analyze the origins and development paths of these knowledge claims and their relationship to challenges regarding what and how we know, we reconstructed these debates according to routines described below. In seeking to understand the relevant knowledge dynamics through reliance on existing theory, we identified gaps. Specifically, we identified knowledge claims that have become established despite weak connections to evidentiary processes that typify science and co-production and that do not map onto existing critiques of established models. Analysis of these specific instances led us to propose the emergent mode of knowledge production as a complementary resource for theorizing knowledge dynamics and social change.

Our study is based on documents produced by scientists, citizen scientists, non-governmental organizations, governmental agencies and journalists, mainly based in the USA. These text records were identified through a combination of systematic, theoretical and snowball sampling (Bryman, 2016). The three debates that structure our analysis – (i) the monarch population, (ii) the monarch's dependence on milkweed and (iii) the significance of policy efforts that classify monarchs as pollinators – served as the primary filter in a systematic review of scientific research, public commentary and policy processes. This review was premised on keyword searches of specialized databases (such as LexisNexis® Academic and Cornell University Library meta-database consisting of more than 100 databases, e.g. Web of Science, International Bibliography of the Social Sciences, JSTOR) and online search engines. Theoretically informed sampling structured a targeted search for information from actors important to our research who were likely under-represented by the initial search (e.g. citizen science coordinators, active committees tasked with making policy recommendations). After identifying promising lines of inquiry, we used snowball sampling to collect additional material by following discussions back in time and across diverse organizational settings. The final source material includes scientific articles, government and NGO reports, citizen science newsletters, press releases, blogposts, websites and newspaper articles. The documents cover a timespan of nearly a century. The digitalization of communication in combination with increasing engagement of science, policy and publics with monarchs has resulted in recent years accounting for a disproportionate volume of our materials.

In using the texts to trace the development of central knowledge claims, we identified cumulative process of scientific inquiry (linear model) and interactive, synthetic processes (relational model). In recognizing that neither of these well-established models usefully explains some effective knowledge claims, and reflecting on the dynamics that gave rise to those specific claims, we propose the emergent model as a complementary resource for probing science–policy–practice interfaces. The case of monarch butterfly conservation allows us to assess the value of the emergent model as a complement to the linear and relational models.

The Case of the Monarch Butterfly

The Monarch Butterfly as a Conservation Icon

The monarch butterfly (*Danaus plexippus*) and its 2500-mile-long fall migration from Canada to Mexico has fascinated generations of observers (Brower 1995). Each fall monarchs migrate from their summer breeding grounds in northeastern North America to a cluster of about 12 mountaintops at 3000 m above sea level in Michoacán,

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Mexico. After several months the monarchs again take flight. They migrate north and lay eggs on milkweed host plants in the Gulf States of the southern USA. Subsequent generations do the same as they make their way on the northward segment of the annual cycle. Monarch caterpillars strictly consume milkweed leaves (plant species in the genus *Asclepias*), and adults only consume water and floral nectar.

Based on capacity to bridge social boundaries, the monarch butterfly has attained cultural status and political power. Through social engagement that spans more than a century, and through interactions among scientists, citizen scientists, environmental advocates, artists, educators, school children and policy actors, the monarch butterfly has become an international conservation icon (Gustafsson *et al.*, 2015; Oberhauser *et al.*, 2015). Starting in the 1940s, with the research project of Dr Fred Urquhart and Norah Urquhart to track the migration by tagging monarch butterflies, thousands of volunteers have been engaged in the process of establishing knowledge. The efforts to conserve monarch butterflies took off in the 1970s, and in the 1990s the engagement was institutionalized through the foundation of a range of organizations including the Monarch Larva Monitoring Project, Monarch Watch and Journey North. By collaborating with science, citizen science has spread knowledge on the monarch butterfly to people of all ages through elementary school curriculum, media, art and business collaborations (Gustafsson *et al.*, 2015; Ries and Oberhauser, 2015).

While the monarch has long maintained a high profile, the volume and visibility of concern increased markedly in 2014. The leaders of the United States, Canada and Mexico expanded previous commitments to conservation of the monarch at the North American Free Trade (NAFTA) meeting in Mexico in February 2014. During the spring of 2014, milkweed was planted in the White House's kitchen garden. On 26 August 2014, a petition was filed by supporters of the monarch to list the butterfly as 'threatened' under the Endangered Species Act. Following preliminary assessment of the merits of the petition, the US Fish and Wildlife Service initiated a status review of monarchs in December 2014 and their determination is required by 2019.

Policy makers' attention is premised on interactions between decades of construction of the monarch as a cultural icon and scientific accounts of the monarch's acute population decline. For the third year in a row, the count of monarch butterflies over-wintering in Mexico in 2014 was reported to be an all-time low. These numbers were linked to the finding of a long term decline and a 90% drop in the population relative to the mid-1990s. Although the population decline was once attributed to deforestation and illegal logging in Mexico, the major cause of the decline was now claimed to be loss of the monarch larva's food plant, milkweed, in the US Midwest. Loss of milkweed was reported to be the result of a changed agricultural landscape and the expanded use of herbicides that has accompanied widespread adoption of genetically modified herbicide-tolerant corn and soybeans (Brower *et al.*, 2012a, 2012b).

Despite the long history of scientific research, pervasive media attention and action steps by governments, the evidence base supporting core claims about monarch butterflies and how to conserve them can be questioned. Ambiguity applied to the current situation is reflected in the 600% increase in the monarch population as estimated for 2016 relative to 2014 (Monarch Watch, 2015). Critical engagement with the evidence base of powerful knowledge claims raises important questions about the construction, strength and potentially perversities of knowledge derived from what Palmer has referred to as 'actionable science'; science capable of generating policy-relevant outputs that are 'compatible with the form or pace of changes in social norms, behaviors, or governance structures' (2012, p. 6). While engaging citizens in science, in conservation and in policy debates is widely understood as important to mobilizing the state, countering corporate influence over discourses and policy decisions, and reshaping cultural engagement with environment, the case of the monarch highlights contradictions and risks. The monarch's popular status catalyzes knowledge production and social change and at the same time it potentially undermines the knowledge base on which conservation is founded.

The Monarch Butterfly Population

Questions about long-term trends in the monarch population have been of great interest for decades. In 1955, Urquhart reported to his network of one thousand or so Citizen Scientists that very few monarchs were observed in 1952, suggesting major continental-scale fluctuations (Urquhart, 1955). In the decades that followed, monarch enthusiasts and scientists continued to monitor the population. Today there are several well-established citizen science projects (e.g. Monarch Watch, the Monarch Larva Monitoring Project and Journey North) and a series of

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yearly censuses structured around the work of trained volunteers (e.g. WWF's Mexico census; the North America Butterfly Association Butterfly Counts). These data are regarded as an essential input to the scientific practice of adding new knowledge to what is already known, allowing the knowledge frontier to move forward. Any questions about the legitimacy of citizen science's contributions have been resolved by subjecting citizen scientists' data to the same evidence standards and peer-review processes as scientific data. These accountability measures allow unorthodox activities to fit neatly into the linear process of knowledge production.

A limited number of analyses of long-term trends in the monarch population have been produced since the 1970s. Swengel has published studies based on summer butterfly counts (see, e.g., Swengel, 1995, 2009). The analyses showed a growing downward trend in the population since the mid-1990s. Two additional studies of long-term trends were published in 2012. The first study used data from the overwintering counts in Mexico to show a long-term decline in the population (Brower *et al.*, 2012a). The second article relied on fall migrating survey data and revealed a stable population (Davis, 2012).

Davis's (2012) article was criticized by Brower *et al.* (2012b). Focusing on methodology, Brower *et al.* (2012b) attempted to discredit any interpretation of the contrasting results as pointing to ambiguity about long-term trends in the monarch population. Brower *et al.* (2012b) insisted that differences stem from Davis's poorly done science. The two studies and the critique were followed by three years of silence. As a consequence of lack of active debate about the disagreement, the dominant understanding of the monarch population as in decline remained intact.

In September 2015, the debate resumed in a special issue featuring seven studies 'with the overarching goal of identifying long-term trends in... [the monarch butterfly's] abundance or distribution outside of the wintering period' (Davis and Dyer, 2015). All studies were based on data gathered through citizen science projects. In the journal introduction, Davis and Dyer (2015) restated Davis's claim from 2012 that a long-term population decline is not observed outside the overwintering sites in Mexico.

Again, Davis's arguments and analytical techniques were met by criticism from some of the most distinguished monarch scientists (Pleasants *et al.*, 2016). This critique was published together with a commentary from Dyer and Forister (2016). Dyer and Forister (2016) argued that the dispute pointed to unanswered scientific questions, and monarch scientists need to focus attention on what is causing the conflicting results of population trends through application of well-known and trustworthy scientific methods.

Inamine *et al.* (2016) took up this challenge through study of the relationship between regions in the monarchs' multigenerational migratory cycle. The study confirms that there is a long-term decline in the population at the overwintering grounds in Mexico, and there is not a decline in the population during the summer breeding generations. Thus, despite decline in Mexico, the population is able to rebound during the summer in the USA and Canada. The study argues that something happens to the population during the time of its migration that results in a decline in Mexico. The cause of this decline is identified as a pending research question, with lack of nectar sources and habitat loss as leading contenders. With these results Inamine et al. (2016) problematizes both the dominant view of how to understand trends in the monarch population and the causes of population fluctuations.

The analysis by Inamine *et al.* rejected a dominant role for milkweed in the monarch's population fluctuations. Earlier, Pleasants and Oberhauser (2013) studied the relationship between declining numbers of monarchs in Mexico and a decline of milkweed in the US Midwest since the mid-1990s. The study showed a correlation between the two, and linked expanded use of herbicides in corn production to reductions in the monarch population in the Midwest. In 2014, Flockhart *et al.* addressed the question by developing a year-round population model. The study confirms the result reported by Pleasants and Oberhauser (2013): loss of milkweed affects the monarch population negatively. In line with other studies of population trends, the model by Flockhart *et al.* (2014) relies heavily on expert judgments. Through '[i] independent elicitation of survival estimates, [ii] an anonymous review of the group results, and [iii] a second round of elicitations where experts were allowed to modify their original responses after having seen the group results' (Flockhart *et al.*, 2014, p. 158), educated guesses have been turned into estimations of reality. The design of the Flockhart *et al.* study has pushed the boundaries and standards of scientific evidence within the field of ecology by relying on professional judgments and interactions among professionals to parameterize models.

As represented by this review of studies of the monarch population and the drivers of population dynamics, scientific knowledge can be represented as a linear process with complementing elements of relational processes.

Science builds cumulatively on existing data and knowledge. Credible knowledge derives from sustained, disciplined, collaborative work. Despite disagreements among scientists and ambiguity attached to the status of the population and appropriate ways to represent it, the assembled knowledge on the monarch butterfly has come to specify an environmental problem and principal causes.

Monarchs and Milkweed

As farming intensified over the past 20 years through expanded planting of genetically modified Roundup Ready corn and soybeans, scientists and advocates voiced concerns regarding the consequences of greater reliance on herbicides for weed control and associated loss of milkweed in the monarch's flyway (Oberhauser *et al.*, 2001; Pleasants and Oberhauser, 2013).[1] Echoing Urquhart's emphasis on milkweed in the 1970s (Urquhart, 1973, 1975), a call to conserve and plant milkweed emerged in the last decade as a prominent message among citizen science organizations, NGOs and popular media (e.g. Monarch Watch, 2008). Education and public outreach programs focused on growing milkweed and nectar flowers in private and public spaces have become a central conservation strategy, and there is an active market for milkweed seeds and seedlings (e.g. Monarch Watch's Milkweed Market). The scope of public engagement is reflected in First Lady Michelle Obama planting milkweed in the White House kitchen garden in 2014.

The importance of milkweed and the practice of planting it were established in communities of experts and in popular culture before scientific evidence of a link between milkweed loss and the monarch population was presented by Pleasants and Oberhauser in 2013. Prior to scientific statements, efforts to conserve and reestablish milkweed have been based on experiences and judgments that have been elaborated through contact between scientists and citizen scientists. This interactive, relational knowledge process has allowed practical experience and educated guesses to fill knowledge gaps and inform conservation strategy. Online networks such as the Monarch Watch Blog and Dplex-L listserve have become important means to synthesize and communicate knowledge (e.g. Monarch Watch, 2008). Fora including the 2001 Monarch Population Dynamics Conference and the 2012 Monarch Biology and Conservation Meeting are key sites for deliberation among scientists and aficionados. Interaction between scientists, citizen scientists and environmental managers has given rise to new knowledge claims that are based on combinations of academic processes, accumulated everyday experiences and people's eagerness to take positive actions (Ries and Oberhauser, 2015). The science of Pleasants and Oberhauser (2013) and Flockhart *et al.* (2014) served to confirm practical conclusions already in circulation.

The status of genetically modified crops in the narrative of decline of milkweed and risks to monarchs raises important questions about how this knowledge has become established. In 1999 monarchs were at the center of a politicized debate about risks attached to genetically modified Bt corn. The controversy was fueled by an extensive public outcry in response to a laboratory study showing that monarch larvae that ate milkweed dusted with Bt corn pollen had elevated mortality (Losey *et al.*, 1999).[2] Subsequent scientific research showed that Bt corn did not pose a threat to monarchs, and the issue was determined to be a non-problem (NRC, 2000; Oberhauser *et al.*, 2001; Pool and Esnayra, 2001). Despite these scientifically derived conclusions, sustained public controversy contributed to protests and legislation against GM crops in the United States and Europe (Grabner *et al.*, 2001), which demonstrates how social change sometimes emerges in a manner disconnected from scientific conclusions. Questions posed by transgenic technologies in relation to farming, food, ecosystems, health, duties of the government and rights of individuals relative to corporations have produced sustained, intense politics. These politics are an element of the context in which knowledge claims about risks to monarchs emerge and become established in popular culture, expert communities and policy networks.

Recent scientific studies based on citizen science data have come to show how some efforts to establish milkweed have produced unexpected consequences (Satterfield *et al.*, 2015). Planting tropical milkweed (*Asclepias curassavica*), which does not naturally senesce in the autumn like native milkweeds (e.g. *A. syriaca*, the most common eastern

[1]Roundup Ready seeds tolerate exposure to glyphosate, a herbicide. This trait encourages farmers to use glyphosate liberally for weed control (decreased reliance on mechanical cultivation). The result is fewer weeds in and around fields, including milkweed.
[2]Bt refers to insecticidal toxins produced by the bacteria *Bacillus thuringiensis*, which have been engineered into crops to reduce damage from caterpillars.

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milkweed), presents monarchs with a year-round food source. This change in resource availability has implications for migrating and overwintering populations (Satterfield *et al*., 2015). Knowledge and practice that was supposed to aid the butterfly has instead introduced a potential new threat. Looking ahead, the findings by Inamine *et al*. (2016) that the cause of the monarch decline in Mexico occurs during the fall migration, after the migrating generation has become independent of milkweed, may destabilize scientific and popular understanding of the link between milkweed and monarch population trends.

Understanding of the importance of milkweed in relation to monarch populations grew out of diverse social processes in which scientific evidence has not been particularly central. The significance of milkweed and milkweed planting emerged from experts' judgment and the willingness of a large number of people to take up the task of planting milkweed. Past controversies and ongoing debates about risks attached to GMOs likely contributed to the establishment of milkweed as a *cause célèbre*. Scientific evidence later reinforced the importance of milkweed to monarch populations. Follow-on scientific investigation problematized conservation practices and causal claims: specifically risks attached to establishment of non-native milkweed varieties and the institutionalization of a conservation strategy that may eventually prove to be unfounded.

The Monarch Butterfly as a Pollinator

In the spring of 2014, the conspicuous absence of monarch butterflies from agricultural landscapes elevated the status of this charismatic species on political agendas. Surprisingly, monarch conservation was incorporated into a wider problem definition: decline of native pollinators. Through this association, the monarch has been enrolled into a debate about biodiversity, food security and socioeconomic wellbeing. The most prominent expression of this was President Obama's memorandum on pollinators, which in 2015 resulted in a federal strategy to promote the health of honey bees and other pollinators, which explicitly included monarch butterflies (White House, 2014, 2015). Pollination has recently become identified as an 'ecosystem service', a benefit stream derived from nature that has value to humans and therefore merits the attention of citizens and policy makers. Attention to the health of populations of pollinators derives from concerns about agriculture and food security, as loss of pollinators is linked to vulnerability and increasing costs for farmers and for consumers of fruits and vegetables (Kosek, 2010; NRC, 2007).

Framing monarchs as pollinators has advanced despite scientific demonstration that monarchs are rather poor pollinators of milkweed (see, e.g., Betz *et al*., 1994; Fishbein and Venable, 1996). Further, by virtue of their large size, the mechanics that structure the way the butterfly contacts most flowers and the relative abundance of other flower visitors, monarchs are not recognized as important pollinators of other species. This assessment is well established among scientists, and the monarch is publicly reported as not having a large and measurable impact on humans: 'If monarchs became extinct tomorrow, it is likely that the impact on our material well-being would be negligible' (Oberhauser and Solensky, 2004, p. vii). So, how has the monarch butterfly come to be defined by the President of the United States as a pollinator and as relevant for food security, and how has this questionable classification been legitimated?

In terms of scientific understanding of the monarch butterfly as a pollinator, nothing has changed. The monarch butterfly is still regarded as a poor pollinator. The monarch butterfly has, however, been championed by citizen science organizations and environmental NGOs as an indicator species for pollinators, 'the canary in the coal-mine' or in this case 'the canary in the corn field' (Brower, 2001). The alliance between monarchs and pollinators has ostensibly strengthened both interest groups: those defending monarchs and those defending pollinators and biodiversity, more broadly. Pollinator species, which have just recently become a focus of scientific monitoring and popular attention, are strengthened by being able to draw on knowledge derived from a long history of studying the monarch and by attachment to the star power of this iconic organism. The monarch butterfly has been strengthened by layering utilitarian economic and public health claims on top of ethical and aesthetic arguments for its conservation. The connection that has been constructed between monarchs and pollinators, however tenuous from a scientific perspective, has expanded the potency and reach of the actors, including the policy makers. The multiplicity of loosely connected actors that contribute knowledge and project meanings onto monarchs and pollinators has transformed the process of knowledge production from being regulated by scientific standards or deliberative principles to instead being based on collisions between diverse symbols and interests in public spaces. Engagement

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with the monarchs and their conservation has taken a surprising and unlikely leap through which the butterfly has emerged as an agent of food security and a source of ecosystem services on which our wellbeing depends.

By enrolling a highly diverse collection of scientists, aficionados, activists and public officials, as well as mass culture, the monarch has emerged as a symbol for pollinating species in the absence of scientific evidence or public debate about this specific claim (cf. Gustafsson *et al.*, 2015). The monarch has been made a flagship species not because it is a good pollinator or because some segment of the public understands it to be one, as would be expected according to the linear or relational logics of knowledge production. Instead, the monarch has emerged as a pollinator based on concern about loss of biodiversity, risks attached to modern agriculture, the star-power of monarchs and policy makers' need to take some public action. It is important to note that the 'lumping' of monarchs with pollinators has occurred through engagement with knowledge claims produced linearly (i.e. scientifically) and relationally (i.e. through co-production). In other words, a foundation of validated knowledge makes this (mis) representation possible and potent.

Discussion and Conclusions

The case of monarch butterfly biology and conservation demonstrates the value of recognizing multiple, intersecting processes of knowledge production. The well-recognized linear and relational models of knowledge production usefully describe many elements of the relevant history, but establishment of powerful, surprising and sometimes contradictory knowledge claims that cannot be explained through reliance on existing models leads us to argue for recognition of 'emergent' processes of knowledge production. This third model addresses how effective knowledge claims – i.e. knowledge that serves to structure technical, social, and policy actions – arises out of engagement of an increasingly diverse set of actors and mounting pressures on public figures. As problems, solutions and symbols become salient to mass publics, knowledge derived from science and formally constituted platforms for public engagement mingles with ideas and commitments derived from sources increasingly disconnected from traditional bases of expertise. New knowledge emerges from these relatively unstructured, unmediated interactions.

We have identified decay and projection as two processes through which engagement of mass publics yields new knowledge. Enrolling monarch butterflies in a national policy initiative to stem loss of native pollinators – and the establishment of widespread public understanding of monarchs as pollinators – contradicts established scientific consensus on the topic, and this represents an example of decay. The way in which milkweed loss and milkweed planting have become established elements of conservation planning represents an example of projection. The monarch's dependence on milkweed was established in public consciousness through generations of ecological educational programming and passionate engagement of citizens who seek to take concrete actions in support of monarchs. This stylized and perhaps reductive understanding of monarch ecology has been projected onto policy and perhaps onto science.

In taking steps to theorize and empirically assess emergent knowledge, we identify science and knowledge derived from co-production as central. The case of the monarch – specifically, the histories of debates about population changes, availability of milkweed and the relevance of monarchs in efforts to conserve native pollinators – suggests that a foundation of scientific knowledge and a set of diverse, vibrant platforms for popularization are enabling conditions for emergent knowledge to become a relevant feature of policy decision making and popular understandings. Additional case studies are needed to assess this claim.

Our treatment of emergent knowledge and the processes that give rise to it is not normative. In identifying these dynamics we do not assert a hierarchy of knowledge, and we do not assign blame regarding dysfunctional science–policy–practice interfaces. Like the linear and relational models, the emergent conception of knowledge production serves to support explanations of empirically observed processes. As an ideal type, the model is a resource for making sense of complex dynamics. It is not a stand-alone representation of the real world. We introduce this model to complement the established linear and relational models.

As a conservation icon subject to acute, well-publicized risks, monarch butterfly conservation is a rich empirical example of interactions and intersections of linear, relational and emergent processes of knowledge production. Energy is introduced by environmental change and by engagement of mass publics, position scientists and

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advocates, who have cultivated positions of authority over decades, to shape policy and social change. Under these conditions, knowledge, policy and practice can take fast and surprising turns. Experts must navigate opportunities to advance conservation as well as risks attached to extending legitimacy to knowledge claims characterized by substantial ambiguity. The concept of emergent knowledge has potentially significant implications for practices of knowledge brokerage and professional ethics (see, e.g., Honkela *et al.*, 2013; Pielke, 2007).

Recognition of emergence applied to knowledge production points to the power of public engagement. The social hierarchies between science and non-science, represented in both the linear and relational models, dissolve fully in emergent knowledge production. While opening up of categories of whose knowledge counts and realization of the catalyzing potential attached to interactions between science, advocacy and mass publics imply great potential, the erosion of commitments to evidence and to accountability applied to knowledge claims introduces significant risks. This same tension applies to the Internet as a resource for enhancing governance. Emergent knowledge implies potential for propagation and perhaps institutionalization of beliefs that are not supported by evidence.

In highlighting the relevance of knowledge claims that emerge through processes that can be described as unmediated and unaccountable, we identify the importance of critical approaches to citizen science, public engagement with science, and environmentalism (see, e.g., Dickel and Franzen, 2016). Science communication understood as translating scientific information and method for lay audiences is not enough. In an era of information overload and the lies of Trumpism (Leonhardt and Thompson, 2017), critical reasoning skills and research skills (i.e. source and fact checking) must accompany efforts to engage affect, advance empowerment and exercise voice.

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