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PERSPECTIVE

Co-designed Projects in Ecological Research and Practice

Better together: Building an engaged conservation paleobiology science for the future

Gregory P. Dietl[1,2] | Stephen R. Durham[3] | Cheryl Clark[3] | Rebecca Prado[3]

[1]Paleontological Research Institution, Ithaca, New York, USA
[2]Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, New York, USA
[3]Florida Department of Environmental Protection, Tallahassee, Florida, USA

Correspondence
Gregory P. Dietl
Email: gpd3@cornell.edu

Present address
Rebecca Prado, WSP USA, Tallahassee, Florida, USA

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Abstract

1. Making decisions about natural resource conservation is often difficult because of a lack of longer-term data, which are needed to provide a frame of reference for identifying and choosing appropriate responses to threats impacting species, ecosystems, and the benefits they provide to people.
2. Despite the promise the field of conservation paleobiology holds for using geohistorical data and insights to provide this longer-term perspective, examples of successful implementation are uncommon.
3. Over the past decade, many conservation biology researchers and practitioners have turned to knowledge co-production to overcome this same challenge. Co-production prioritizes collaboration between academic and non-academic partners to produce actionable knowledge that better aligns with conservation practitioners' needs and concerns.
4. We argue that the conservation paleobiology community must similarly build collective competence to engage more effectively in shared "learning spaces" where actionable knowledge is co-produced. We draw from our experiences with the Historical Oyster Body Size project and lessons learned from other fields to identify key attributes of actionable geohistorical knowledge and the meaningful co-production processes that produced it.
5. Familiarity with these concepts will benefit conservation paleobiologists and all researchers who aspire to help develop longer-lasting, defensible and more equitable solutions to complex conservation problems presented by a changing world.

KEYWORDS
actionable science, community of practice, conservation paleobiology, co-production, engagement, knowledge-action gap, research-implementation gap, translational paleoecology

1 | INTRODUCTION

Faced with the rapid pace of current changes in climate and land use, society has never been in greater need of a longer-term (>decadal) perspective to guide ecosystem management and sustainable resource use. Conservation paleobiology has emerged as a powerful approach that uses the wealth of information stored in geohistorical records—sediment cores, fossils and other natural archives—to provide a longer-term perspective on how species and ecosystems respond to environmental changes and a growing human population, which is often unavailable when conservation and resource management decisions are made (e.g. Barnosky et al., 2017; Dietl et al., 2015; Dietl & Flessa, 2011; Fordham et al., 2020; see Groff et al., 2023, and references therein, for examples of conservation paleobiology in action). By unearthing the secrets of the past, conservation paleobiologists can help craft equitable,[1] defensible and durable conservation solutions for people and nature. Yet, many conservation paleobiologists are often disheartened by the limited impact of their science on informing decisions, which contributes to the view—shared with other conservation sciences—that a "gap" exists between the science and practice of conservation (Arlettaz et al., 2010; Cook et al., 2013; Cooke et al., 2021; Dillon et al., 2022; Groff et al., 2023; Knight et al., 2008; Roux et al., 2006).[2]

Several reasons have been put forward to explain this gap. Part of the issue is the hegemony of a traditional, linear model of science, which treats knowledge production as a unidirectional flow of scientific information between researchers and conservation practitioners (Bertuol-Garcia et al., 2018). In a linear model, researchers generate knowledge relevant to a conservation problem, then transfer that knowledge to a "loading dock" (e.g. the peer-reviewed scientific literature; Beier et al., 2017; Cash et al., 2006) where it is hoped it will be "picked up" by or "trickle down" to practitioners to solve a problem (Figure 1a). In turn, practitioners are often discouraged by "loading dock" scientific evidence, which seldom aligns with their needs and concerns (Bertuol-Garcia et al., 2018; Cook et al., 2013; Savarese, 2018). Proposed solutions to problems are often too vague or uncertain (Arlettaz et al., 2010; Bertuol-Garcia et al., 2018), inaccessible (Cooke et al., 2021; e.g. behind journal paywalls), not useful because of scale issues (Bertuol-Garcia et al., 2018), out of sync with policy windows (Cooke et al., 2021; Rose et al., 2020), too expensive to implement (Cook et al., 2013; Roux et al., 2006), politically impractical (Roux et al., 2006) or steeped in technical jargon to be meaningfully interpreted (Fazey et al., 2005). This suite of factors is likely only exacerbated by unfamiliar paleontological concepts. A different approach is urgently needed. Given the shortcomings of the linear model, conservation biologists and practitioners have more and more (though not yet universally) advocated for greater emphasis on the co-production of knowledge—the intentional decision of researchers and practitioners to work together on equal terms—to increase the impact of science in conservation practice and policy (Beier et al., 2017; Bertuol-Garcia et al., 2018; Gerber et al., 2020; Lemos et al., 2018; Roux et al., 2006; Figure 1b). Despite gaining momentum within the broader conservation community, co-production has rarely been practiced by conservation paleobiology researchers (Groff et al., 2023).

This perspective aims to motivate others both within and beyond the conservation paleobiology community to adopt the co-production model by documenting a "bright spot"—a situation where paleoecological evidence has successfully informed resource management practice (sensu Cvitanovic & Hobday, 2018; Groff et al., 2023). We first discuss co-production as a tool for developing actionable science (Beier et al., 2017; Cook et al., 2013; Enquist et al., 2017).[3] Second, we share our experiences with the Historical Oyster Body Size (HOBS) project, reflecting on the co-production processes and attributes of the knowledge produced that helped pave the way to a successful outcome. Our goal is to distill key lessons that we think conservation paleobiology researchers—and other researchers in the wider conservation community—who desire to engage with conservation practitioners need to know. We conclude by making recommendations for building and maintaining an engaged conservation paleobiology science for the future.

Throughout, we emphasize the benefits of a necessary and desirable cultural shift within the conservation paleobiology community to equal the one taking place in conservation biology, from a mode of linear knowledge transfer—the stockpiling of geohistorical facts on the "loading dock"—to one of engaging in shared learning spaces (sensu Buschke et al., 2019; Roux et al., 2006; Stern et al., 2021; Toomey et al., 2017) to generate more opportunities for the co-production of actionable science among conservation paleobiologists, conservation practitioners and other stakeholders. Our view is that by adopting knowledge co-production, conservation paleobiology can better understand and serve the wider conservation community's needs and deliver on its social contract with society (sensu Lubchenco, 1998).

2 | CO-PRODUCTION AS A TOOL FOR ACHIEVING ACTIONABLE SCIENCE

Over the last decade, many conservation biologists and practitioners have turned to knowledge co-production to increase the usability of science beyond the academy (Beier et al., 2017; Gerber et al., 2020). In practice, however, co-production can mean "different things to different actors in different contexts" (Zurba et al., 2021, p. 3). Therefore, we ground our discussion (and motivation for practicing knowledge co-production) in Beier et al.'s (2017, p. 289) definition of co-production as the "collaboration among managers, scientists, and other stakeholders, who, after identifying specific decisions to be informed by science, jointly define the scope and context of the problem, research questions, methods, and outputs, make scientific inferences, and develop strategies for the appropriate use of science" (Figure 1b).[4] Co-production is believed to produce context-specific

[1]Here, we use "equitable" in the broadest sense of the term to mean fairness in how people are treated or conservation actions are planned and implemented (Bennett et al., 2021).

[2]Framing the impact of science on conservation action as a "gap" is also thought to have the negative psychological effect of increasing "anxiety in scientists (and particularly early career scientists)" seeking to engage with practitioners, "disempowering some of them from even trying" (Cvitanovic & Hobday, 2018, p. 1).

[3]We follow Beier et al. (2017, p. 289) in defining actionable science as "data, analyses, insights, predictive models, or planning tools based on scientific research that support decision-making in biodiversity conservation."

[4] Co-production shares its conceptual foundation—that is, research does not operate as a one-way flow from science to society—with several other related approaches (e.g. use-inspired research (Wall et al., 2017) and translational ecology (Enquist et al., 2017; Hallett et al., 2017; Lawson et al., 2017; Schwartz et al., 2017)).

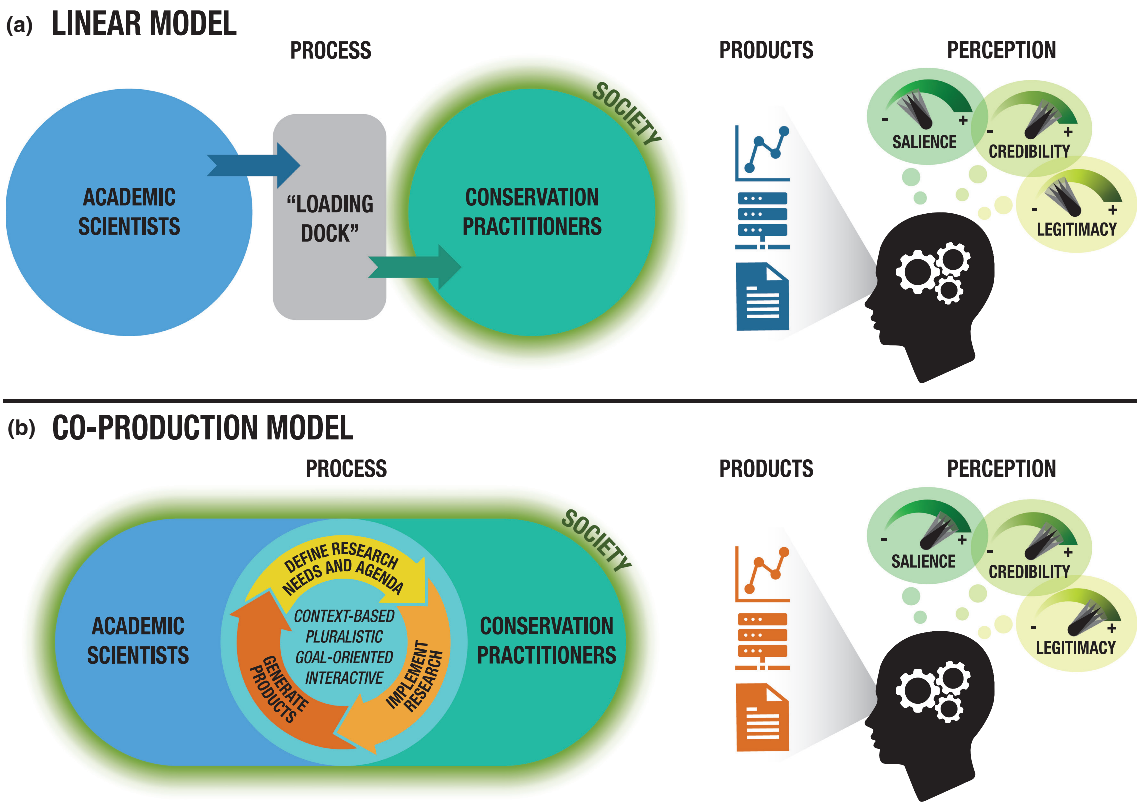

FIGURE 1 Two forms of knowledge production and consequent end-user perceptions of solutions to conservation problems. (a) Linear model of knowledge production assumes unidirectional knowledge flow between science and practice; to solve conservation problems, scientists (working outside of the science-practice interface) "push" evidence-based solutions (left arrow) to a "loading dock" (e.g. the peer-reviewed literature) where they are "picked up" by conservation practitioners (end-users) for translation into action (right arrow). (b) Co-production model of knowledge production assumes reciprocal knowledge flow between science and practice; conservation practitioners, scientists and other stakeholders (i.e. the people invested in and affected by conservation decisions) jointly create actionable knowledge by working together to define research needs, set research agendas, implement research and generate products (e.g. data, publications, decision support tools) to solve conservation problems that they could not achieve alone. Products generated via a co-production process that is situated in a particular place or problem (context-based), includes diverse voices and ways of knowing and doing (pluralistic), clearly defines desired outcomes (goal-oriented) and is highly interactive are more likely to be perceived by end-users as salient, credible and legitimate (right side of panel b) than those produced by a linear model (right side of panel a). The "wobble" depicted in the gauge needles illustrates that people with different knowledge, values and experience can view the same information differently.

knowledge that better fits management/policy needs and concerns than that developed by more traditional models (e.g. the "loading dock" approach; Figure 1a). Importantly, beyond producing knowledge, the co-production process can cultivate social learning (Reed et al., 2006), build social networks, foster social capital (Pretty & Smith, 2004) and develop actions that contribute to conservation (Norström et al., 2020).

3 | THE NATURE OF THE KNOWLEDGE CO-PRODUCTION PROCESS

Although some practical advice on how to navigate the research-implementation gap in conservation paleobiology is available in the literature (e.g. Boyer et al., 2017; Conservation Paleobiology Workshop, 2012; Dillon et al., 2022; Flessa, 2017; Kelley et al., 2018; Kelley & Dietl, 2022; Savarese, 2018), little consideration has been given to the processes that facilitate meaningful knowledge co-production. According to Norström et al. (2020), all effective co-production processes are: (1) context-based, (2) pluralistic, (3) goal-oriented and (4) interactive. These attributes (which are not mutually exclusive) are useful guideposts, as well as a starting point, for understanding what sets effective co-production processes apart from others. Here, we share some practical insights we learned from our work on the HOBS project that helped make it a success—lessons that can be used to help guide others seeking to align their research goals with conservation needs.

The HOBS project, which benefitted from strong, trusted[5] prior relationships between some of the team members, was co-produced by a collaboration of conservation paleobiologists at the Paleontological Research Institution (PRI) and resource managers at the Florida Department of Environmental Protection (FDEP) Office

[5]Trust can be construed by people in different ways. Here, we follow Stern and Coleman (2015) in defining trust as an individual's willingness to accept vulnerability in the face of uncertainty. Trust is a common theme that intersects with each of the four attributes of effective co-production research processes.

of Resilience and Coastal Protection (RCP). The primary research focus was to fill an information gap in habitat monitoring records using estimates of historical oyster body sizes from dead oyster shells that accumulate and become buried within an oyster reef as it grows over time. Decades of paleoecological research indicate that these buried shells are a readily accessible record of long-term average conditions on decadal to centennial timescales (e.g. Dietl & Durham, 2016; Durham et al., 2022).

The HOBS project was situated within the context—the environment in which co-production research operates (Djenontin & Meadow, 2018)—of the FDEP Statewide Ecosystem Assessment of Coastal and Aquatic Resources (SEACAR) project. The purpose of the SEACAR project is to enhance scientifically based local and state submerged and upland management and policy decisions within RCP managed areas by aggregating and synthesizing coastal habitat monitoring data from a variety of agencies, programs and studies into an online database and a public website reporting results of habitat status and trends analyses based on the aggregated data. The SEACAR project, funded by the Florida Coastal Management Program (FCMP) since 2016, was conceived following the response to the 2010 Deepwater Horizon oil spill disaster in the Gulf of Mexico, during which RCP lacked the consolidated data needed to respond to urgent requests for documentation of pre-spill habitat conditions within the submerged lands managed along Florida's gulf coast. In addition to improving RCP's responsiveness to habitat data needs in the event of another environmental crisis, the uses of the assessment results include prioritizing management and restoration efforts, gaining new insight into environmental conditions and identifying data and information gaps in order to improve local, regional and statewide management and policy development. Understanding these broad ecological, social and economic dimensions of the resource management problem was fundamental to achieving effective co-production research in the HOBS project. In other words, the match between a project's outcomes and the context of the problem it aims to address largely determines how relevant resulting research findings are for decision making (Enquist et al., 2017; Lawson et al., 2017; Norström et al., 2020; Wall et al., 2017).

Co-production of research is unavoidably a pluralistic process, centering on the inclusion of diverse voices and knowledge systems (e.g. academic, resource management, etc.) to enhance the potential of producing defensible, equitable and workable solutions to complex resource management challenges (Cooke et al., 2020). The SEACAR project's co-production process therefore began with multiple regional stakeholder meetings involving a mix of technical and leadership-level staff from over 70 different academic institutions, federal and state agencies and non-governmental organizations (NGO) to collaboratively identify the highest priority habitats for management, and the best indicators to use to evaluate their condition, based on expert opinion, data availability and utility for decision-makers.[6] Many stakeholders who contributed to the development of SEACAR recognized a need for data to document the condition of oyster (or other shellfish) habitats, which provide multiple ecosystem services (e.g. water filtration, nitrogen removal) in nearly every coastal RCP managed area (Coen et al., 2007). One of the priority indicators to evaluate oyster habitat condition that was mentioned by numerous stakeholders was oyster size because it is related to multiple life history traits (e.g. age class structure, fecundity, sex ratios). However, although today oyster size is commonly measured as part of monitoring efforts for natural and restored oyster habitats around the state (Baggett et al., 2015), it was not initially included in the SEACAR project because the periods of record for almost all oyster body size datasets from Florida are limited—only ~20% of oyster size datasets identified in the early phases of the SEACAR project included data from before the year 2000 and nearly 40% of them encompassed only the last 5 years or fewer. This tension between the importance of the size indicator and the lack of historical data was critical to motivating the use of an unproven, novel source of historical information for oyster habitat assessment—making the HOBS project possible.

Co-production benefits from jointly defined goals that are agreed upon in advance (Norström et al., 2020). The HOBS project was initially developed as a National Oceanic and Atmospheric Administration (NOAA) Coastal Zone Management (CZM) Project of Special Merit (PSM) proposal through the FCMP (though it was ultimately funded through FCMP's NOAA CZM Section 306 funding rather than as a PSM), which presented an opportunity for team members to learn about each other's interests, priorities and goals. Open-mindedness, willingness to listen to others' views, humility and being reflexive about positions and biases in this formative stage of the project helped build (and maintain) an inclusive co-production process (Boyce et al., 2021; Cvitanovic et al., 2021; Gerber et al., 2020; Stern et al., 2021). For instance, both RCP and PRI had a strong interest in the problem of filling some of the temporal gaps in oyster size information. Although differing interests were also accommodated (e.g. RCP prioritized maximizing geographic coverage to justify the inclusion of oyster size class as a SEACAR indicator and it was important to PRI that the project results be reported in a scientific journal), commitment to a shared goal of providing historical context for comparison with the live-population size data created a feeling of ownership and mutual accountability among HOBS project team members (Cheruvelil et al., 2014).

Sustained interaction of the HOBS research team occurred throughout the co-production process, including jointly framing and designing the research, conducting fieldwork, collecting, analysing and interpreting data and disseminating the knowledge produced, which helped ensure the usability and relevance of the project results to end users (see also Gerber et al., 2020). Early interactions were especially important in establishing goodwill and fostering a shared sense of understanding to create an environment that nurtured joint reflection and learning (Beier et al., 2017; Enquist et al., 2017; Gerber et al., 2020; Norström et al., 2020). For instance, few of the state employees on the project team had

[6] For more information about the SEACAR project's co-production process and partners, and the HOBS project's data and protocols, see: https://data.florida-seacar.org/ and additional links therein.

collaborated with conservation paleobiologists before and vice versa, which required development of cross-disciplinary rapport and trust in each other's expertise. The great majority of the relationships' substance was developed while working long hours together, in person, during fieldwork (often in hot temperatures and other challenging conditions). Subsequently, regular (~weekly) interactions among members of the project team continued, primarily remotely, as data were collected, analysed and reported. The sustained engagement helped the PRI researchers empathize with the practitioners' perspectives (needs, values), and thus how paleontological science could potentially be used to help address management/policy needs (Gerber et al., 2020; Sarkki et al., 2015).

Since 2018, the HOBS project has successfully generated location-specific estimates of oyster size from radiocarbon-dated samples collected from several localities in RCP managed areas around the state. All data and protocols from the HOBS project were archived and shared in the publicly available online SEACAR project database,[6] which integrates data collected by many different monitoring programs in a standardized format, along with thorough metadata (e.g. program information, protocols, etc.) and geospatial information. The processed and curated HOBS project samples were similarly deposited in the PRI research collection as a public resource for future reference and additional research.[7]

4 | WHAT MAKES CO-PRODUCED KNOWLEDGE ACTIONABLE?

A well-designed co-production process should foster research results that are perceived as salient, credible and legitimate (Cash et al., 2003; Figure 1b). These attributes present a useful framework for explaining why some science is used and other science is not (Cooke et al., 2020). Reflecting on these attributes in the context of the HOBS project helps to further clarify some of the factors that contributed to the project's success.

Salience refers to the relevance of co-produced knowledge to policy and societal needs and concerns (Cash et al., 2003; Sarkki et al., 2015). One critical factor influencing the salience of the HOBS project was that the timing and scale of the created and shared knowledge matched management needs (Rose et al., 2020; Sarkki et al., 2015). Rose et al. (2020) showed that the opportunity for research results to inform and improve conservation decisions often occurs within brief, discrete policy windows (see also Norström et al., 2020). The HOBS project was no different. The project was developed early enough in the SEACAR project life cycle that size class was retained as one of the indicators for oyster reef habitat condition, and there was sufficient time for the HOBS project data to be included in the SEACAR analyses and products. Another serendipitous aspect that increased salience was that ~85% of the dead shell samples collected were radiocarbon dated post-1966 (Durham et al., 2022)—the year the first Florida Aquatic Preserve was established. Because the Florida Aquatic Preserves are each managed primarily with reference to the habitat conditions at the time the preserve was established, data from deeper in the past would have been less relevant for management needs.

In addition to aspects of timing and temporal scope, salience of knowledge produced can also be affected by its accessibility—how readily accessible, readable and intelligible it is to potential users (Sarkki et al., 2015)—which, if not adequately considered, can undermine the usability of scientific evidence (Cook et al., 2013; Cvitanovic et al., 2016). Accessibility in the HOBS project was increased by taking the same size measurements from dead shells that are collected by living oyster monitoring programs around the state and working the geohistorical sampling into a well-respected oyster monitoring protocol that had already been in use by RCP, making the HOBS project size data readily understood (sensu Sarkki et al., 2015) by anyone familiar with the living oyster monitoring protocols.

Credibility encompasses the (perceived) scientific quality, believability and trustworthiness of the knowledge produced during a co-production research process (Cash et al., 2003; Sarkki et al., 2015; Figure 1b). The credibility of the information provided by the HOBS project was enhanced by several factors, including the use of an accepted paleoecological research approach (e.g. Dietl & Durham, 2016) and transparency about the uncertainties and limitations of the science (Cooke et al., 2020). For instance, we were clear about the limitations (i.e. time averaging, preservational biases) of paleoecological data and their differences with respect to data from real-time monitoring programs of living oyster populations. Finally, the HOBS project data were subjected to the same robust, independent subject matter expert review process (sensu Cvitanovic et al., 2021) as all of the other oyster data aggregated for the project, which involved a multi-organization team of Florida oyster experts[6] who reviewed the oyster data collection programs, decided which would be comparable for inclusion in the SEACAR meta-analysis, gave input on how the data were analysed and then were engaged again to evaluate confidence in the status and trend findings.

Legitimacy is the degree to which knowledge produced during a co-production process is perceived to balance and consider the values and beliefs of multiple stakeholders (Cash et al., 2003; Cook et al., 2013; Sarkki et al., 2015). The HOBS project derived much of its broader legitimacy (buy-in) from being embedded within the SEACAR project, which, as we previously described, has a strong record of pluralism.[8] The HOBS

[7]PRI Research Collection, https://www.priweb.org/research-and-collections/research-collection; Accession #1860. PRI's capacity as a museum to curate and archive the HOBS project samples for future study was seen by RCP as a selling point for the collaboration, presenting an opportunity to pursue new HOBS research on short notice as supplementary funding became available, without the need to invest time and funding for additional fieldwork.

[8]We recognize that research results that are perceived as legitimate to those who are "in", that is, part of a co-production process (e.g. the SEACAR stakeholder group), does not always mean that those who are outside of this group of stakeholders will perceive the results in the same way, even those with whom the findings are ideologically compatible. As Clark et al. (2016, p. 4574) stated: "inclusion created through collaboration is never complete".

project was also selected for implementation by SEACAR leadership, demonstrating agency buy-in, a factor that was enhanced by the dissemination of project updates and solicitation of feedback from future data users on monthly statewide SEACAR meetings, as well as the participation and input from field staff who advised on the project design and participated in the fieldwork within their managed areas. Finally, the HOBS research team itself was critical to legitimacy of the knowledge produced because it helped ensure that the relevant specialized academic expertise that was required was involved while keeping the project grounded in the practical needs of the SEACAR project.

Salience, credibility and legitimacy of co-produced knowledge are all tightly coupled (Cash et al., 2003; Sarkki et al., 2014); although these attributes often are synergistic, efforts to increase one of them can come at the expense of the others (Cash et al., 2003; Sarkki et al., 2014). One example in the HOBS project—a trade-off between salience and credibility—was how to balance the clarity of HOBS findings for a less-technical audience based on the needs and expectations of the SEACAR project with incorporating the significant complexities and uncertainties inherent in interpretations of geohistorical data (i.e. the clarity-complexity trade-off; see Sarkki et al., 2014 for descriptions of this and other types of common trade-offs), such as the sample age uncertainties associated with the radiocarbon analysis and the taphonomic history of each sample. Communicating these uncertainties credibly (i.e. via highly technical statistical outputs) runs the risk of decreasing saliency for SEACAR end users who may find the results unintelligible (Cook et al., 2013). Accepting this trade-off was unavoidable, but we carefully considered how to present HOBS project results in an interpretable way for multiple audiences, including designing different versions of summary plots with different levels of detail. Despite these efforts, the HOBS data may still be ignored in some decision contexts—an acceptable risk to bear to ensure scientific rigour (credibility) was not compromised, which, if it was, could increase the risk of the results being contested and/or misused (Cooke et al., 2020; Sarkki et al., 2014; Stirling, 2010).

5 | OUTSIDE THE COMFORT ZONE

Viewing the production of geohistorical knowledge that is salient, credible and legitimate as an emergent outcome of a collaborative, social research process that involves not only academic scientists but also contributions from conservation practitioners and other stakeholders who hold different values, beliefs and interests forces a reframing of the concept of a "gap" between conservation science and practice (sensu Toomey et al., 2017). Rather than thinking metaphorically about the gap as something that needs to be "bridged" (by the transfer of scientific evidence to practitioners via the "loading dock"), we can think about a "learning space"[9,10] (the blurred boundary area at the intersection of science and practice) where knowledge co-production occurs (Toomey et al., 2017; Figure 1b). Roux et al. (2006, p. 11) made a similar point when they argued that knowledge is not a "thing" to be transferred, but rather a "process of relating" that involves partners negotiating meaning together (see also Stern et al., 2021; Toomey et al., 2017).

An implication of reframing the gap between science and practice as a shared learning space is that conservation paleobiologists must conduct their research in ways that challenge traditional views about how science works (Buschke et al., 2019; Clark et al., 2016; Elliott et al., 2018; Roux et al., 2006; Stern et al., 2021; Toomey et al., 2017). Increasing the usability of science for conservation cannot only be a problem of searching for evermore precise scientific facts (truths) to make sound conservation decisions (i.e. the linear model of science; Clark et al., 2016; Rose, 2018; Figure 1a). A scientifically derived conservation solution is not automatically superior to other ways of knowing. Instead, researchers need to accept that solving complex conservation problems often requires a "post-normal" science (sensu Buschke et al., 2019; Funtowicz & Ravetz, 1993; Rose, 2018), which is "context-sensitive" (Nowotny et al., 2001), problem-focused and contingent on bringing multiple ways of knowing together (e.g. combining explicit scientific facts and tacit knowledge based on an individual's experiences) to deliberate and negotiate meaning (Clark et al., 2016). Failing to recognize this reality risks encouraging the widespread belief of science as an "ivory tower" disconnected from the practical and ethical complexities of everyday life (Rose, 2018). This claim is hardly new. As Nowotny et al. (2001, p. 1) stated in their account of the dynamic relationship between society and science: "science can no longer be regarded as an autonomous space clearly demarcated from the "others" of society." A much closer, intentional collaborative relationship between science and society in co-producing research does not mean, however, that scientific rigour is sacrificed in the process. As Cooke et al. (2020, p. 366) stated, the underlying goal of researchers should always be to produce "rigorous, unbiased, and reproducible science".

Buschke et al. (2019) suggested that post-normal science is a vehicle for conservation biologists (and we would add for conservation paleobiologists too) to more effectively "occupy" learning spaces to catalyse more impactful knowledge creation and utilization. In this light, the gap metaphor is better envisioned as a deficiency of skills

[9] Toomey et al. (2017) suggested calling these spaces "research-implementation spaces", "research-practice spaces" or "knowledge-action spaces".

[10] Our use of the term "learning space" is resonant with the Japanese concept of "*Ba*" (translated as "place") that was advanced in Nonaka's theory of organizational knowledge creation (Nonaka et al., 2000; Nonaka & Konno, 1998). *Ba* is where knowledge is converted (by interaction of tacit and explicit knowledge) into more usable forms (Nonaka, 1994; Nonaka et al., 2000). Because actionable knowledge for conservation requires that scientific and other ways of knowing (e.g. resource management knowledge) interact with each other and converge, Nonaka's model offers a powerful way of conceptualizing how knowledge convergence toward actionable knowledge works in practice. See Roux et al. (2006) and Stern et al. (2021) for a more thorough introduction to Nonaka's theory and its broader implications for resource management and conservation biology, respectively.

needed to span boundaries (Stern et al., 2021). The HOBS project research team honed many of these boundary-spanning skills "on the fly" through trial and error, or better yet, trial and success—a task made easier by prior exposure to some of the ideas discussed in the co-production literature—but a more efficient approach is not only desirable but attainable. Although a recent survey of self-identified conservation paleobiologists indicated that the field has yet to reach consensus on how applied it should be in practice (Dillon et al., 2022), we believe that learning how to engage effectively in shared learning spaces is a necessary advance within the conservation paleobiology community to empower researchers to engage and collaborate with conservation practitioners in the co-production of paleontologically informed conservation and resource management.

6 | LEARNING THE ART OF KNOWLEDGE CO-PRODUCTION

The demand for researchers who are prepared to engage in co-production research is expected to grow as the complexity and urgency of the environmental problems society faces continue to escalate in coming years (Schwartz et al., 2017). Despite a recognition of this need, academic training in conservation paleobiology often falls short of teaching practical skills to engage with conservation practitioners and other stakeholders (Conservation Paleobiology Workshop, 2012; Kelley et al., 2018, 2019; Savarese, 2018). Harnessing the power of knowledge co-production in conservation paleobiology, therefore, will require a cultural shift in the field's values, norms, priorities and practices. What to do and how to start are big questions.

First and foremost is taking time to nurture and enhance the development of interpersonal competencies (or capacities; sensu Clark et al., 2016; e.g. conflict resolution, empathy, trust building skills) needed to engage effectively in co-production learning spaces (Kelley & Dietl, 2022). For instance, an ability to negotiate is as essential for researchers who wish to engage with "wicked" problems (i.e. involving contested situations that lack clear solutions and that are deeply embedded in disagreements among stakeholders), as it is for amicably finding solutions to the banal disagreements bound to come up in less contentious research situations. In our experiences with the HOBS project, for example, it became clear as laboratory work progressed that our original goal of processing the samples from at least 30 reefs was not possible if samples from all burial depths were processed. RCP favoured using the remaining time in the project period to maximize the geographic coverage and statewide completeness of processed samples, whereas PRI favoured prioritizing the temporal (i.e. burial depth) coverage for each reef even though fewer than 30 reefs would be completed. Inventing other options and exploring the merits of each before deciding what to do (sensu Fisher et al., 1991) helped create a climate of joint problem-solving that led to a mutually acceptable solution to the shared problem that dovetailed the interests of both RCP and PRI.

While modifications to academic training programs can help to address competency gaps in negotiation and other interpersonal skills (e.g. mediation, leadership, etc.) in the future (Kelley & Dietl, 2022), waiting for the next generation of versatile researchers to be trained by such transformative programs is not enough. Experiential learning in the form of immersive learning-by-doing opportunities must become a priority to empower early-career researchers (White et al., 2015). Taking advantage of existing co-production collaborations (Cooke et al., 2021) and internships with conservation-related NGOs and government agencies can help the current generation of students build a diverse skill set and gain practical knowledge to address conservation problems through valuable, real-world experience (Conservation Paleobiology Workshop, 2012; Evans & Cvitanovic, 2018; Flessa, 2017).

Researchers who are interested in co-producing their research with conservation practitioners—often motivated by selfless reasons, such as a desire to conduct socially responsible science (Singh et al., 2014)—could take ownership of their own education (Clark et al., 2016; Cooke et al., 2021; Schwartz et al., 2017) and redouble efforts to:

1. read papers on the topic (Beier et al., 2017),
2. identify mentors with practical co-production experience (Clark et al., 2016; Cooke et al., 2021; Lawson et al., 2017),
3. apply for fellowship opportunities that require partnering with an NGO or public agency (e.g. The Nature Conservancy's NatureNet Science Fellows Program),
4. attend resource management meetings,
5. seek out conservation training programs (e.g. Future Earth's Earth Leadership Program),
6. serve as faculty liaisons to, or seek employment with, NGOs and government agencies (Savarese, 2018),
7. participate in management collaboratives (Savarese, 2018; Toomey et al., 2017),
8. engage with boundary organizations (e.g. Science for Nature and People Partnership), and
9. take advantage of sabbatical ("visiting scientist") opportunities and formal "scientist-in-residence" programs that embed researchers in management environments (Clark et al., 2016; Conservation Paleobiology Workshop, 2012; Cook et al., 2013).

In fact, S. Durham's arrival as a National Academies of Sciences, Engineering and Medicine Gulf Research Program Science Policy Fellow with RCP was a catalyst to developing the HOBS project because some of his prior paleoecological work (Dietl & Durham, 2016) inspired RCP staff to see a potential solution to the paucity of oyster size data for SEACAR.

The emerging National Science Foundation (NSF)-funded Conservation Paleobiology Network[11] also holds promise in building a community of practice in which positive experiences of actively participating in learning spaces can be shared, especially as

[11]https://conservationpaleorcn.org/

more of its members engage in, and experiment with, co-production practices themselves. Because people learn how to translate science into action as they are mentored into a community of practice (Lawson et al., 2017), strategies to facilitate meaningful knowledge co-production must become part of our shared repertoire of resources to enable collective reflection and learning.

Significant challenges still lie ahead, however, before co-production can become a cultural norm in conservation paleobiology. Knowledge co-production can be a slow process that is not guaranteed to succeed, especially as the complexity of environmental, economic and societal challenges and diversity of stakeholders involved increases (Rubert-Nason et al., 2021). Barriers to participation may seem unsurmountable, even for those who desire to engage. For instance, professional incentive structures in academia (i.e. tenure and promotion) are set up to reward publishing peer-reviewed journal articles and not engagement with conservation practitioners (Arlettaz et al., 2010; Kelley et al., 2018; Norström et al., 2020; Savarese, 2018). A research culture of speed in the "accelerated academy"—that rewards the relentless addition of peer-reviewed papers to the "loading dock"—disincentivizes participation, especially by early-career researchers who must (understandably) prioritize research productivity over conservation action to secure their future academic survival. Indeed, the production of scientific publications for the HOBS project has been slower than purely academic collaborations, in large part because of the relatively lower priority of academic publishing in a resource management setting. Although actionable, technically rigorous baseline information on oyster size was ultimately achieved, the context of the SEACAR project did not include testing hypotheses or investigating the causes of any changes detected, given that the overarching goal was limited to providing status and trends analyses for RCP managed areas. Pursuing the HOBS project thus involved accepting higher-than-normal risks of (perceived) failure than was typical for PRI researchers, who had no guarantee of ending up with research results that were publishable in high-impact scientific journals.[12] Beyond time constraints and the pressures to publish, other barriers to engagement commonly discussed in the co-production literature include lack of financial resources (Rubert-Nason et al., 2021), institutional constraints (Hallett et al., 2017; Singh et al., 2019), pressures to act (Rubert-Nason et al., 2021), cultural norms (Singh et al., 2014) and risk aversion (e.g. potential reputational damage; Cooke et al., 2021; Hallett et al., 2017; Rubert-Nason et al., 2021).

Acknowledging the reality of these challenges does not mean that a co-production future in conservation paleobiology is reasonably unlikely to happen. Several authors (e.g. Beier et al., 2017; Enquist et al., 2017; Hallett et al., 2017; Kelley et al., 2018; Safford et al., 2017; Savarese, 2018; Schwartz et al., 2017; Singh et al., 2019) have detailed the kinds of institutional changes that could support effective co-production practices, including broadening the conception of how conservation scientists are evaluated (e.g. modifying promotion and tenure criteria to acknowledge the less easily quantified time investments associated with co-produced research (Arlettaz et al., 2010; Beier et al., 2017; Savarese, 2018; Singh et al., 2019), establishing funding opportunities specifically to support co-produced research that addresses practitioner needs (Beier et al., 2017; e.g. the NSF and Paul G. Allen Family Foundation Partnership to Advance Conservation Science and Practice program) or that enable redirection of projects to better align with changes in decision context (Montana et al., 2020) and creating stewardship awards for community-based conservation activities (Singh et al., 2019) and fellowship-training opportunities focused on broadening engagement skills among researchers (Schwartz et al., 2017)). Other solutions mostly remain unexplored and even unimagined. Ultimately, despite the potential for success stories like the HOBS project to catalyse change, the onus for change rests squarely on the shoulders of those in power within institutions (Singh et al., 2019). Instilling an ethos of co-production in the conservation paleobiology community of practice will require investments of time, acceptance of risk and openness to learning. Together we can enhance awareness, share ideas and rise to the challenge of delivering on the field's social contract with society (sensu Lubchenco, 1998).

7 | CONCLUDING REMARKS—BETTER TOGETHER

The HOBS project illustrates the many benefits of co-production for achieving actionable conservation paleobiology research. Reflecting on our experiences and how the science and practice of conservation intersected with each other allowed us to deepen, to expand and to rethink our intuitions on how paleontological knowledge can become (and stay) relevant for conservation practice and policy. We encourage others to share their experiences with co-production processes, both positive (what worked) and negative (what did not work) and why. For conservation paleobiology researchers who desire to have their science support conservation needs and concerns, co-production may be the single best action that they can take. We need to be eager to change our own opinions, attitudes and behaviours, and be open to doing research in new ways. By learning the art of co-production, we could transform the conservation paleobiology field and improve public trust in science. If we do not expand the way we know and do, we risk remaining disconnected in the "mental world of academia"—as Soulé (1986, p. 4) warned for the then-nascent field of conservation biology. Our hope is that by inspiring conservation paleobiologists and others to strive for different ways of doing research, together we can accelerate the use of paleontological science in conservation and resource management to build a better tomorrow for people and nature.

[12] Willingness to accept a higher-than-normal risk of failure was also necessary for RCP staff, who were investing in a relatively unproven type of information without prior knowledge of the temporal period or resolution of the resulting body size data.

AUTHOR CONTRIBUTIONS

Gregory P. Dietl led the writing of the manuscript, with contributions from Stephen R. Durham. All authors contributed to the content and editing of the manuscript and approved the final version. The views, statements, findings, conclusions and recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of the State of Florida, NOAA or any of their subagencies.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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ORCID

Gregory P. Dietl https://orcid.org/0000-0003-1571-0868
Stephen R. Durham https://orcid.org/0000-0003-1299-0569

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