Infrastructure and Vocation: Field, Calling and Computation in Ecology

Steven J. Jackson
Cornell University
301 College Ave, Ithaca NY
sjj54@cornell.edu

Sarah Barbrow
University of Michigan
818 Hatcher South, Ann Arbor, MI
sbarbrow@umich.edu

ABSTRACT
HCI studies of computational change in the sciences have made important design and analytic contributions, to other fields of science and to HCI itself. But some of the longer-term effects and complexities of infrastructural change in the sciences aren't easily captured under short-term, design- or artifact-centered accounts. Drawing on extended ethnographic study of computational development in ecology, this paper explores the relationship between new computational infrastructure and the nature of *ecology as a vocation*: roughly, the deeply held sense of what it means to 'be' an ecologist, and to 'do' ecology. We analyze in particular the nature of the field and field work as a central site of ecological practice and identity; how new computational developments are remediating this crucial relation; and the emergent vocational values that new and more computationally-intensive forms of ecology may give rise to.

Author Keywords
Infrastructure; collaboration; science; ecology; vocation; values in design.

ACM Classification Keywords
H.m. [Information systems]: Miscellaneous.

INTRODUCTION
"If there is a heaven, and I am allowed entrance, I will ask for no more than an endless living world to walk through and explore. I will carry with me an inexhaustible supply of notebooks, from which I can send reports back to the more sedentary spirits…" -- E.O. Wilson, 2011

"I went into ecology to be in nature, and now all I do all day is sit at my $#%!ing computer." -- informant interview, 2009.

HCI and CSCW studies of scientific collaboration have revealed important effects and challenges associated with the introduction of new computational infrastructure into the practice of scientific work. These include the mediating effects of distance and distributed action [11,24]; the challenges of collaboration across institutional and organizational lines [2,3]; dynamics and tensions attending the development of infrastructure [13,25,29]; the complexities of standardization, governance, and new forms of articulation work as the form and scale of scientific collaboration changes [22]; and the significance of temporal forms and rhythms as sites and challenges of collaborative work [14,16]. But these represent only partial responses to the deep change aspirations of computational change in the sciences. Can new computational tools and practices change how we do, imagine, and experience the work of science? Can investment in projects produce changes in fields? Can new computational infrastructures support new kinds of science, within and across existing fields? Can advanced scientific computing indeed help foster, as former NSF Director Arden Bement has argued, "new cultural communities… that collaborate and communicate across disciplines, distances, and cultures"? [23]

Answering these sorts of questions may require design and analytic strategies that extend beyond short-term and tool-centered considerations of sociotechnical change. The present paper offers one such possible reframing. Building on social science theories of infrastructure and vocation, HCI studies of e-science and cyberinfrastructure, and several years of ethnographic fieldwork around the adoption of new computational infrastructure in ecology, it argues that some of the most profound and important questions around computational change in the sciences may in fact be *vocational* in nature, producing basic changes in the sense of what it means to 'be' an ecologist, and to 'do' ecology. As developed here, vocation speaks to both individual and collective experiences of work, and to the distinctive "structures of feeling" that sustain forms of life and activity as meaningful for their participants. It also speaks to the ways in which individuals are called to particular forms of work, and the kinds of values and commitments that hold them once there. In both ways, vocation connects current processes of computerization and infrastructural change to larger and deeper trends in the experiential, normative, and practical histories of scientific fields.

At the same time, we argue that vocation in ecology and other sciences is also a profoundly *material* affair, rooted in specific object relations (with tools, equipment, and routinized interactions with things like water, grass, trees,

CHI 2013, April 27 – May 2, 2013, Paris, France.

air, and dirt), and grounded in specific places (canonically, 'the field'). From this perspective, vocation is *not* the extra human bit, value, feeling, or superstructure that's added to a concrete and separate world of artifacts and things. Nor is it inherently a throwback, the pang of regret or nostalgia for older traditions of work that are in process of being suppressed or supplanted. Instead, vocation is blended, vital and dynamic, constituted at the intersection of human and material orders that are themselves being born, reproduced, and subtly altered all the time.

To take an outside example of vocation and its rooting in the object world: to be a small-scale farmer in mid-century Northern Ontario was to be connected to a local agricultural economy in which value and livelihoods could be sustained, and forms of community in which social relations of kinship, standing, and meaning could play out. But it was also about a very specific set of relations to *objects* – crops, animals, equipment, etc. – along with a series of practical operations that connected the work and skill of the farmer to the objects in question. Such object relations and the vocational sense they anchored were simultaneously individual and social in nature: one's personal sense of competence and identity as a farmer were grounded in such operations, but they also functioned as markers of social assessment, and were routinely used to assess competence, membership, and standing within the wider community. The thickness and depth of such object relations became particularly apparent at moments of breakdown and change – movements into retirement, the introduction of new farm equipment and techniques, the absorption of erstwhile farmland into expanding urban hinterlands, etc. Such changes had large and ramifying effects on the meaning and experience of farm work, with important consequences for the nature of farming as a vocation.

The vocation of the computer programmer, by contrast, is rooted in a different set of object relations: with computers and code (and sometimes things like coffee and diet coke!), but also to the particular places and worlds of collaboration that are built around them. As our own conversations with IT specialists reveal, these too can be disrupted: by movements to other forms of code, hardware, and programming languages, or by movements into management positions that sever or attenuate the object relations that drove and sustained early interest and excitement in the work. Molecular biologists moving into administrative roles have sometimes described this sense of loss and regret as 'bench nostalgia': but we have heard countless parallel instances of 'code nostalgia' among the coders-turned-managers of contemporary IT firms.

Here then is our argument. Among its many other effects, computational change and development in the sciences displaces and reconfigures the object worlds of science, including key locations and material interactions through which work is accomplished. In doing so, it may alter and disrupt the vocational values that have historically shaped commitment and engagement to an ecological way of life. But this is neither a simple nor pure experience of loss (as an account based in nostalgia might suggest): reconstitution of the object world also gives rise to *new* structures of feeling, which arise and travel unevenly across the loosely integrated worlds of collaborative science, and operate in partial independence from the instrumental considerations that typically guide formal programs of investment in this space. It is therefore possible for participants to simultaneously love and use new tools while regretting what they do to the fundamental values and experiences that first drew them to the field – a sense of ambivalence periodically encountered in our field work.

Bringing concepts like vocation into HCI scholarship has important work to do in deepening and extending our spheres of analysis, around computational development in the sciences but also many other sites in which HCI research and design efforts confront complex and deeply-rooted traditions of practice and value. It may help us think towards new modes of human engagement with infrastructure and the broader object worlds around us. And it may help the field's ongoing project of extending analytic concern from instrumental users to fully realized humans, embedded and constituted in networks of meaning, value, and commitment.

OBJECTS, INFRASTRUCTURE, AND VOCATION IN SCIENTIFIC PRACTICE

At first glance, nothing could seem further from HCI than the decidedly old-fashioned language of vocation. For early Christian theologists, vocation emerged to account for ways in which individuals were 'called' to a religious life, whether of a monastic or lay variety. As early as the 5th century, St. Augustine of Hippo [28] used the term to distinguish true from false callings, and the conditions under which individuals ought properly to abandon the secular world for a life of God. Over the course of the European Middle Ages, the concept was broadened and secularized to include a range of craft and trade-based industries. Given the medieval embedding of work in relations of social identity, standing and power, such craft-based instances of vocation ran deep and thick; 'miller,' 'ferrier,' or 'tanner' described an economic or occupational identity, but also something like a "total way of life," with normative and moral elements inextricably tied to the material and social organization of work [6].

Vocational concepts get drawn into the lexicon of modern science with Max Weber's influential 1919 essay, "Science as a Vocation" [30]. Like St. Augustine, Weber mobilizes the term to explain the distinct normative dimensions attending a way of life that had, by Weber's day, come to be regarded in more instrumental or operational terms. Individuals called to science, argued Weber, are drawn and answerable to a particular set of values and practices: distinctions between fact and value; a singular devotion to research; a personal grounding in the community of scientists pursuing similar questions and problems; and the kind of humility and common-mindedness associated with a willingness to see one's work surpassed by others.

The normative dimensions of Weber's analysis get taken up and elaborated in the classic sociology of science pioneered by Robert Merton. Writing in the 1930s and early 1940s, Merton [20,21] identifies an "ethos" built around four core values – "universalism," "communism," (meaning something closer to communalism), "disinterestedness," and "organized skepticism" – that separates science and scientists from other spheres of life. Such values describe the characteristics of an authentic scientific life and the nature of social organization in the scientific community. But they also describe the individuals likely to be drawn to fields of work constituted in this way. There is therefore something like a seamless and mutually reinforcing web that binds the worldview and social organization of science to the personality types that practice it: the ethos of science calls forth the kinds of agents that sustain it; and to be a scientist is to be drawn and responsive to this call. As recent work by Shapin [26] on the U.S. information and biotech industries emphasizes, this sense of vocation remains real and live, and continues to drive how scientists perceive, practice and assess scientific virtue, including under the uncertainties and complexities of emergent industry-based research.

Vocational concepts as developed by Weber, Merton and Shapin have important things to offer contemporary analyses of science, including HCI efforts to build and study the development of new computational infrastructure in the sciences. They address questions around the normative and experiential constitution of fields that disappear under more functional or instrumental descriptions of tools or data. They speak to problems around choice and motivation towards a scientific life with important outcomes for inclusion and representation. And they offer strategies for bridging the worlds of experientially grounded norms and values with the social organization of scientific work, without making one a simple offshoot or derivative of the other. At the most general level they can help restore a picture of the sciences as rich and complex human worlds, grounded in networks of norms, values, and commitment.

But vocational ideas in their classical form also inherit key limits and blind spots. The first concerns their divorce from the material world, a casualty first of the ascetic bent of early Christian theology and later the founding divide of the modern social sciences, through which "social facts" were separated from the natural and material worlds in which they were embedded [7]. Through most of its trajectory in Christian theology, the call to God is placed in implicit or explicit opposition to the world of things; 'following the call' was therefore framed as an act of renunciation, the giving up of worldly things and material entanglements rather than, say, a movement from one set of material practices to another. The same ascetic spirit shows up in Weber and Merton, for whom vocation exists as a purely normative phenomenon, reflecting values and commitments with no obvious grounding in the material conditions of scientific work. More recent work in the sociology of science (including Shapin's) has challenged this separation, emphasizing the situated nature of scientific knowledge and the important roles of place, bodies, and material culture in the constitution of scientific knowledge and practice [10,17,19,27,29].

The second problem with Weber and Merton concerns the underspecified category of science at the heart of their analyses. For Weber writing in 1919, broad-scale concepts like vocation could still be meaningfully addressed at the level of science as a whole; twenty years later, sociologists like Merton would still find it adequate to speak of "the normative structures of science" in the singular. But most ensuing work in the history and sociology of science has challenged this assumption, pointing to the vast diversity of interests, experiences, and values that characterize and differentiate the practice of science across sites and fields. Thus, while appeals to science in general continue to exert broad cultural appeal, the kinds of norms and values embedded in vocation may operate more clearly and consistently at the disciplinary or even sub-disciplinary level. (Indeed, if norms and values *did* operate as robustly and consistently at the pan-scientific level as Weber and Merton imagined, many of the difficulties around designing computational infrastructure at the interface of separate disciplinary cultures would be significantly lessened!).

Finally, neither Weber nor Merton explain or acknowledge the potentially *dynamic* character of scientific vocation. Rooted in timeless and placeless ideals, classical notions of vocation provide little insight as to how engagement with new practices, places, and tools – the specific object relations that shape and sustain a scientific way of life – may alter the basic structures of feeling that characterize the practice and meaning of science as a vocation.

On this set of questions, science-focused work in HCI and allied fields has important insights to offer. Star and Ruhleder and subsequent scholars [13,29] have emphasized the embeddedness of scientific infrastructure, pointing to the tight and layered integration of technical form with systems of knowledge and social practice, and the often unequal distribution of consequences attending infrastructural change. Work in value-sensitive design has sought to bring design practice in medical and scientific fields into better alignment with questions of sociocultural value and meaning [5]. Scholars like Forsythe [8], Hine [12], Jirotka [15] and Fry [9] have documented ways in which assumptions and values may be built into new computational infrastructures across various fields of science, some of which may founder on or contradict long-standing traditions of value and meaning within and across fields.

As this work indicates, programs of computational development in the sciences may carry practical and normative implications that extend beyond the instrumental hopes and concerns that typically guide them. In the sections that follow, we build on these efforts by considering the deep grounding of experiences of fieldwork and 'the field' in ecological practice and identity, and the complicated interactions between scientists' relations to field and the development of new computational infrastructures that have begun to transform the practice of research in this area.

COMPUTATION AND INFRASTRUCTURAL CHANGE IN ECOLOGY

The sections that follow report on more than three years of ethnographic fieldwork around questions of computational change, patterns of collaboration, and field- and lab-based practices in ecology. This includes more than 120 interviews with ecological practitioners at more than 20 different research sites, with special but not exclusive focus on the two leading network initiatives in American ecology today: the Long-Term Ecological Research Network (LTER) and National Ecological Observatory Network (NEON). Interviewees included ecological personnel ranging from lead PIs, information managers, and education and outreach coordinators to post-doctoral researchers, graduate students, field technicians, and NSF program officers. Typical interviews lasted between one and three hours, and in several instances one or more follow-up interviews were conducted with the same participants. In addition, we have conducted participant observation at more than a dozen ecological research sites, network planning, and professional association meetings over a roughly three year period. Interviews have been fully or partially transcribed by the research team and/or hired transcriptionists, and taken with our observational field notes have produced more than two thousand pages of data. This data has in turn been coded per grounded theory precepts using NVivo qualitative analysis software applied through successive rounds of open and structured coding. The themes of fieldwork, infrastructure and vocation reported here represent one of the strongest threads emerging from this work.

The dates covered by our fieldwork coincide with a period of significant ferment in American ecology, much of it driven by the introduction of new computational tools and infrastructures and concomitant efforts to achieve new forms and scales of scientific collaboration. This includes planning and construction efforts around NEON, a $434 million initiative dedicated to the production of the long-term, standardized, and interoperable ecological data needed to support predictive, integrative, and continental-scale ecological research. But such formal network projects are more than outweighed by the long tail of computational development and adoption unfolding across American ecology more generally. New ground-based sensor networks; satellite and air-mounted remote sensing techniques; new and more sophisticated approaches in ecological modeling; efforts at data standardization, including through new metadata languages and techniques; adoption of GIS, R, and other proprietary and open source software products; new computer-supported forms of scientific education and outreach (including leading 'citizen science' initiatives); the shift to email, web, and new mobile platforms as key sites and media of scientific communication: through these and other mechanisms computation has become a central feature of ecological practice at scales ranging from NEON-like efforts to the practice of individual labs and researchers.

The analysis that follows builds on such experiences to advance three basic empirical claims: first, that vocational values function as both important and specific features of ecological work; second, that shifts in material context, including those associated with the development of new computational infrastructure in the sciences, may challenge and disrupt long-standing vocational values; and third, that many of these effects operate by remediating the crucial relations to field that have long served as a central value in ecological work.

RELATIONS TO FIELD

As work in the history and sociology of ecology makes clear, ecological vocation has long been grounded in the set of experiences, places, and material interactions more generically referred to as "the field." As early as 1789, the term enters the language of natural history through English naturalist Gilbert White's loving portrait of his home parish, *The Natural History and Antiquities of Selborne* [1,31]. Through its early natural history phase, fieldwork aroused the passions and discoveries of a wide range of ecological investigators, from the meticulous field studies of Carl Linnaeus and the celebrated voyages of Charles Darwin and Joseph Banks, to the more colorful experiences of pirate-naturalist William Dampier [4], who periodically took a break from knocking off merchant vessels and distant outposts of empire to record in meticulous detail the flora, fauna, and meteorological conditions of the landscapes he traveled through.

The central role of fieldwork was carried forward, with adjustment, in the transition from natural history traditions to recognizably modern forms of ecology in the first part of the twentieth century. As described by historian Robert Kohler, modern ecology came with a different way of making knowledge, built around a different set of places and material interactions: namely, the rise of the laboratory, and laboratory work, as a key site and infrastructure for ecological investigation. As with subsequent changes attached to computation addressed in this paper, the development of laboratory methods introduced complex and far-reaching changes to the practice and experience of ecology: in the nature and process of the work in its functional sense, but also around such key questions as who would count as a credible producer of ecological knowledge; how such experts were to be trained and employed; where and by what means ecological work was to be accomplished; and potentially significant changes in the experiences, values, and individual types that might be drawn to ecological work in its reformed guise. As Kohler argues, there was no going back:

> The field biologists who came of age in the early 1900s were the first who could not operate exclusively by their own rules on their own cultural ground. They lived in a world of laboratories, in which they felt bound to use lab methods and understood that their own practices and achievements would be judged by lab standards. Few field biologists could ignore these cultural-geographic realities, not even those who would never do an experiment. All lived to some degree in the shadow of laboratory science, and their successors still do [18:4].

But if the import of laboratory techniques and infrastructure changed the practice and constitution of ecology, it did not obliterate the field's natural history roots or crucial grounding in field relations. Instead, twentieth century ecology came to be constituted at the *intersection* of these worlds, a rough dialectic between 'landscapes' and 'labscapes' that had, by the middle part of the century, worked itself out to a distinctive kind of truce or hybrid that has defined the practice and ethos of ecology ever since. In this modified form, the values of field and fieldwork remain a central anchor of ecological practice and identity.

But how, exactly, does the field matter? What role do field and fieldwork play in the constitution of ecological practice and identity? And how is this key relationship being tweaked and modified through the introduction of new computational tools, methods, and infrastructure today?

Going to the field

The ecologists interviewed in the course of our study offered diverse and powerful explanations for the ongoing significance of field and fieldwork in ecology today. Central to these explanations was the importance of fieldwork as a key source of discovery, insight, and surprise. As we heard repeatedly from ecologists of all kinds and career stages, fieldwork can play an enormously generative role as an engine of insight and discovery. As one eminent ecologist reported, "Every major idea of any consequence that I personally have had… has come while I have been in the field, actively involved in the research. These ideas have never ever arisen by me looking at databases here on my computer." Another respondent emphasized the sensory richness of the field as a key source of insight and inspiration:

> I have to be there with my eyes and my ears and my skin looking, hearing, feeling what's going on. The great questions come from seeing, "Wow, what's going on there? How did that happen?" That's not only where the great questions come from, but where the excitement and the enthusiasm for what I do comes from. It's just where I get excited.

Others emphasized the break in the pattern of expectation that emerges from long and deep knowledge of place when confronted with anomalous field-based experiences. A long-time penguin researcher in our study explained how a chance field encounter led to an important breakthrough in a thirty-year program of fieldwork in Antarctica.

> So for three decades we've been weighing these chicks. The bottom line is that you go to these beaches and you capture the chicks and you weigh them and you measure them, then you let them go. And you do this day in and day out and year in and year out. And, you know, it looks like a lot of fun but it's actually just work after a while. Well, one year when I was doing this I suddenly realized that the chicks from a particular colony were all lighter than the chicks from colonies that were just a few meters away. It's one of these things, it's pattern matching. And then you suddenly see this anomaly, right? And you start thinking, "How in the hell can parent Adélies that are feeding in the same region of the ocean be producing heavy chicks in one colony and light chicks in adjacent ones?"

While veteran ecologists can make discoveries in the field by weighing observations against expectations shaped over many years of place-based work, a senior ecologist explained to us how early career ecologists can sometimes use naïveté to their advantage:

> My philosophy has always been that you send someone into the field before they read the literature. The literature has two effects. One is that it allows you to quickly move past what others have thought of and move to the next step and beyond. But the other is that it tends to lock in a world view because you tend to take what you've read to think there's consensus on it and think it's established fact. So there's a delicate balance between those two. You don't want to have to rebuild what others know. That's the whole nature of science, that we build upon each other's knowledge. But you often have to challenge what others know to write those advances. The advantages of going out and sending someone into the system they're studying without having a very detailed background in the question they're after is that they're going to make naïve observations. And when those naïve observations don't jive with what the literature says, there often comes a very useful insight or useful outcome.

Field and fieldwork can also be spaces where integration and mixing of people and their ideas occur, and the theoretical and methodological heterogeneity of ecology is brought into order. Through field-based discussions and ongoing programs of observation, experiment, and collection, ecologists share new ideas, techniques and plans across the disciplinary, biomic, and generational divides that often characterize the training and institutional organization of ecology. This effect is important for senior ecologists, but crucial for students and junior researchers, for whom fieldwork supplies both key apprenticeship opportunities and important rites of passage within the wider ecological community. One junior researcher described how the field influenced their relationship to more experienced ecologists as follows:

> My field research is in a remote, to a certain degree pretty harsh environment and so we just have to work really well with each other and have to become very comfortable with each other to work in that sort of environment. And especially for young ecologists, it fosters an ability to be able to speak more frankly with each other about different ideas. I wouldn't be as hesitant to talk to a principal investigator that I've spent hours in the field working with about an idea, where with somebody else I might feel self-conscious about it and think, "Gosh, I hope this person doesn't think I'm stupid for asking this question." Having spent that amount of time working very closely in an environment like that facilitates a level of being comfortable with each other that just allows that sort of interaction take place.

These kinds of field-based connections can be both enduring and specific, linked to highly particular places and configurations of space. As one leading researcher recalled,

> A very important thing for us in the early years was a building called Darwin Cabin, which was a little three-bedroom cabin at the Notre Dame property that we rented. It was sort of a ramshackle place and the Notre Dame people considered it a dump, so they didn't mind that we rented it. But it had a porch overlooking a lake. It was a wonderful place to talk and it was just the right size for two to five principal investigators to stay. And then the porch was big enough for a field team of up to a dozen or so people to get together, have a beer, have a cup of coffee, talk about how things are going. So our social interaction in the field was really facilitated by the configuration of that space. It may seem like a strange thing to say but that space was a special space and really worked to facilitate the collaboration.

Finally, beyond its distinctive affordances for collaboration, integration, and training, the field and fieldwork has often served as an important grounding for highly personal experiences of value and beauty that, for some researchers at least, constitute a central pleasure and reason for entering ecology in the first place. In many cases, ecological field sites are simply beautiful, and *experienced* as beautiful by the researchers who choose to go there. Many of our informants spoke passionately about the aesthetic or experiential dimensions of field experience, citing particular moments or elements that stood out as personally memorable and significant to their careers as ecologists: the look and feel of wind on prairie grass; late night sunsets on the Alaskan tundra; the collective experience of camp or ship life in remote research environments; the last glimpse of Antarctica at the end of the summer field season.

Such aesthetic experiences were caught up and mixed in complex ways with the more analytic dimensions of ecological work – for example, the tree stand researcher who explained how the smell and "feel" of particular pine stands sometimes helped him gain insight into ecological processes at work in the forest. They also provided a bridge to other forms of natural knowledge, leading to sometimes interesting partnerships between scientists and extra-scientific communities including artists, writers, and amateur naturalists. For many researchers we spoke with, the aesthetic dimensions of fieldwork grounded ongoing passion and commitment to the work and provided a welcome break from the pressures of institutional and everyday life. (Such respondents often also cited the importance of formative engagements with nature in their decision to become ecologists: childhoods exploring prairie grasslands, passions for hiking and outdoor activity, etc.) This provides one additional reason that senior ecologists continue to make time and space for fieldwork (or mourn its loss when such accommodations cannot be made). As one eminent researcher with a large team of highly competent technicians, post-docs and collaborators explained when asked why he still needs to go to the field, "you don't, but your soul will thank you for it."

Losing the field

As argued above, the practice and vocation of ecology have long been rooted in a diverse set of places, experiences, and material interactions collectively known as 'the field.' But new computational infrastructures have begun to enter into this crucial relationship, producing changes (like the laboratory revolution before it) in the basic infrastructure through which ecological work is accomplished and experienced. Low-cost and increasingly sophisticated sensor networks have begun to take on some of the tasks of former field collection teams. Increasingly powerful modeling and reanalysis activities occupy a growing percentage of ecological work (with important variations by disciplinary area). New techniques, practices, norms and mandates for data sharing have begun to erode the one-to-one relation between collection and analysis, giving more ecologists access to data they had no hand in producing. Important new developments like NEON are built around an increasingly prominent commodity model of data, in which centralized and standardized facilities generate data to be offered up for use by the ecological community at large. In many cases, increasingly easy access to data means that ecologists can pursue their work without getting the least bit muddy, wet, bug-bitten or sunburned. These are important and justly celebrated accomplishments. But they may also radically change what it means to be an ecologist and to do ecological work.

This sense of loss was expressed, sometimes keenly, by many of the researchers in our study, including some identified as leaders, champions and early adopters of the computational initiatives and techniques sketched above. One version of this story operates by replacement, in which new computational infrastructure – terrestrial or airborne sensors, automated collection protocols, centralized data platforms like NEON, etc. – begin to supplant the tradition of PI-led ‘boots in the mud’ field programs. Under this model, more and more of the work of ecological research moves indoors and on-screen, consisting of analyses of data produced elsewhere and by others. This fear was sometimes expressed in funding terms, as respondents questioned whether substantial investments in large-scale networking initiatives and computational infrastructure would crowd out money available for existing field-based programs. A second version of the loss story had to do with how new forms of computational infrastructure might be affecting the field experience itself, interrupting and distancing researchers from more immediate and reflective interactions with their environment; as one senior ecologist lamented, “you pay more attention to tending the instrumentation than to the biology that's going on in the field.”

This sense of loss underwrote a number of more specific concerns. One respondent spoke of the importance of field-based ‘native knowledges’ developed through sustained interactions with place and questioned whether new computational infrastructures could adequately capture or support such knowledge:

> I mean there's certain knowledge, like even modelers have to know about things that they can't always get from published papers. There's things you just notice when you're in the field that you don't necessarily otherwise know. It's not necessarily written down anywhere but you just have the feel for it. So, I would fear that we would miss that.

In a purely instrumental vein, the attenuation of site-based knowledges raised important issues of quality control, as opportunities for checking and ground-truthing more automated collection methods or catching confounding influences on field readings declined. More fundamentally, the displacement of traditional fieldwork within ecological practice (if that’s what new computational developments portend) may disrupt a key site in which ecological meaning and identity is produced and the wider social organization of the field secured. Senior ecologists in our study expressed worries that emerging generations of ecologists may graduate and move through their careers without ever developing the deep knowledge of place and system that has traditionally anchored a substantial component of ecological work. Nor is it clear what happens to the crucial work of training, socialization and integration that fieldwork has traditionally supported in a “big data” world. Will students still learn to become ecologists in the same way? How will cross-field connections and the kind of bridging across heterogeneity that has long been a hallmark of collocated fieldwork be supported? And even if all these things are accomplished, how might the fundamental experience of ecology change if the deep aesthetic and experiential pleasures long associated with fieldwork are reduced? Will it still be an ecology that (today’s) ecologists want to practice?

Extending the field

Against the story of loss sketched above, however, must be set two contrasting points. The first is that field and fieldwork in their traditional form have never been an unalloyed good. As many respondents noted, being in the field repeatedly for days, weeks or months poses significant personal challenges, sometimes forcing hard trade-offs between professional interest and ambition and “life in general,” including connections with partners, families, and social networks ‘back home.’ One researcher reported,

> There's always been a tension between family life and a lot of research that I've done. It's an explicit choice between time spent in the field versus time spent with family, during the time when family has time away from school, and time to just do things as a family. And so, that's probably been the biggest constraint on my fieldwork over time. It hasn't been administrative stuff, or other things like that. [Eventually] I decided to drop out of Arctic research and shift my effort to [site Y].

Female ecologists in particular noted tensions between family life and the requirements of fieldwork as a point of difficulty in their careers as ecologists. (Indeed, at the time of writing, a debate raged on the popular ECOLOG listserv about the problems and appropriateness of parents bringing young children into the field). Addressing such challenges sometimes forced hard choices: our respondents reported strategies ranging from changing to less remote field sites or moving towards less field-intensive modes of research (often with regret) to switching into scientific roles with less intensive field requirements (e.g. information management, education and outreach) – and in some cases, leaving science altogether..

Our second point concerns the real and substantial benefits that new computational forms can bring to the practice of ecology, some of which may *extend* rather than attenuate traditional relations to field. As has been widely noted, new tools, techniques, and practices allow ecologists access to new forms and scales of data, extending knowledge around current areas of concern and in some cases leading to fundamentally new kinds of questions. Such systems give access to field sites in new and different ways, allowing ecologists to “be” in the field in ways never before possible. For many, this was experienced as a source of freedom and imagination:

> Well I just totally love technology. It's completely changed the way that I feel free to think about different kinds of questions because data is suddenly cheap. You

don't have to design your thinking around economizing information. And so it opens up, certainly in my own mind and in the students that I'm working with now, a whole different way and freedom of thinking about scaling across time and space.

For ecologists working in remote sites, real-time sensor and other instrument-based readings allowed them to maintain a kind of second-order presence in the field during the many periods of the year they were required to be elsewhere. This included forms of access persisting through other periods of disruption – sabbatical travel, new parenthood, etc. – which helped manage the strains and commitments of fieldwork in more accommodating ways.

Finally, beyond their immediate effects on the relationship between individual investigators and their research sites, new computational infrastructures may help open up the experience of fieldwork, providing forms of access that extend field experience to new audiences. As explored by a growing range of educational, outreach, and citizen science initiatives, new computational infrastructures may go some way towards 'socializing' ecology's traditional field relations, and moving beyond the individual investigator model of what one of our respondents jokingly referred to as "OOPS ecology" (for "Obscure Organisms in Pristine Spaces"). While such initiatives are unlikely to replicate the depth and richness of traditional field experience, they may constitute important venues for sharing that experience more widely, providing partial support for more collective and collaborative relations to field.

DISCUSSION

As the above distillation of our own field materials reveals, fieldwork remains an important and highly valued aspect of ecological practice today. It anchors key processes of discovery and learning. It serves as an important training ground for junior researchers, building skill and knowledge while providing entry into professional communities of practice. It facilitates interaction and understanding across the various forms of difference – disciplinary, organismal, methodological, etc. – that characterize ecological practice today. And for many of our respondents it provides a deep aesthetic pleasure that remains important to the experience and choice of ecology in the first place.

We have also seen how new computational infrastructure, as represented by new remote sensing techniques, recent pushes toward data sharing and reuse, and large-scale networking initiatives like NEON, have begun to intersect this crucial relationship, with effects that may alternately extend or attenuate ecologists' crucial relations to field. It is important that this not be construed as a story of pure loss, or an argument that 'pre-computerization' experiences of field were automatically purer, more direct, or authentic than the emerging practices described here. From the materialist perspective offered here, ecologists' experience of the field has *always* been mediated and in fact substantially accomplished through a world of things. As work by Kohler [18] and others has shown, the material set of ecological work has shifted considerably over the course of its history, and with it its modes of engagement with the field. In the process the forms and values of attachment experienced by ecological researchers (including the core vocational values explored here) have shifted, forming and reforming around successive infrastructural forms. For this reason we argue that emerging computational forms are best said to *remediate* ecology's traditional field relations – enriching some, diminishing others, and possibly leading to new and altered landscapes of value and commitment among the humans who engage this form of work. This is entirely consistent with the broader history of the discipline, including the kinds of gains, losses, and adjustments associated with the early twentieth-century importation of laboratory techniques into ecology. It is also consistent with the dynamic and materially grounded notion of scientific vocation advocated here. If vocation lives not only in the world of affect but is constituted and realized through specific object relations and material interactions, we should expect changes in the basic infrastructure of fields – even where motivated and justified along instrumental lines – to produce changes in the structures of feeling that sustain human action and meaning in this space. Indeed, we should expect no less.

The form of analysis conducted above, though drawing on sources and arguments traditionally distant from HCI scholarship, has important things to offer both the practice and theory of HCI, in particular as it confronts the design and analytic challenges attending the development of new computational infrastructure in the sciences. This is an exciting and important prospect, both for HCI and the wider fields of knowledge we engage. The worlds of ecology and other fields of science are indeed changing, and computation is an important driver of that change. At the same time, there may be ways of going more carefully and thoughtfully forward, some of which raise questions around the nature of HCI, design, and broad social science engagement in this space.

An important general recommendation that follows from our study concerns the need to supplement or replace generic, tool-centered, and aspirational accounts of cyberinfrastucture development with approaches that start from the individual histories of practice and value in specific scientific fields. Such an approach speaks to the dangers and potential pitfalls of generic models of cyberinfrastructure design and tool development, including undifferentiated discussions of things like 'data' and 'infrastructure,' which in our experience may mean radically different things to different fields and researchers. Our study also reiterates the need to take values into account, and attend to both the function and meaning of the practices and artifacts we engage. This includes the deep-seated vocational values that operate within science (and other complex historically-layered practices), and their crucial grounding in field relations. With its history of engagement around questions of infrastructure, collaboration, and the complex intersection between technological form and social values, HCI is well placed to address these points.

There are also recommendations that run somewhat closer to design and policy, with potential bearing on how programs of computational development in ecology are pursued and implemented going forward. As noted above, the relationship between new computational development and ecologists' long-standing relations to their field sites is complex and variable, producing effects that may either attenuate or extend these key relations. This points to potential limits in the commodity data models often associated with large-scale science networks, acknowledged by organizers of such initiatives in the form of concerns around long-term use. More design efforts are needed around technologies that support and extend rather than replace traditional field relations, including efforts to extend the kind of sustained place-based experiences to new and wider audiences (as the more promising citizen science initiatives have begun to do). From a funding perspective, the ongoing significance of fieldwork to ecological practice and training also argues for a balanced funding portfolio that secures the relative strengths and advantages of both large-scale and computationally intensive initiatives and smaller PI-led traditions of field-based work.

Our study also raises important implications for HCI engagement, including how HCI might position its own work vis-à-vis the powerful computational trends working through the sciences (and other complex historical practices) today. These are, as Hine [12] points out, computerization *movements*, shaped by multiple visions and regimes of value, only some of which lend themselves (or are even readily visible) to the expertise of HCI researchers. There are clearly complex "interests" at play – individuals and organizations who see their work and aspirations forwarded by movements towards or away from specific forms of infrastructure development. Actors themselves may be ambivalent and have no fully worked out internal answer as to the desirability (or not) of certain paths forward, either for their own work and experience or the field as a whole; in our own study some of the actors most eloquent in expressing concerns around the current path of computational development were themselves significant new tool adopters, and cited the important instrumental benefits that the new tools could bring.

For HCI researchers, this represents a complex and challenging terrain to navigate. Some of the challenges stem from our own necessarily partial perception of the dynamics, limits, and problems of the fields we encounter, and the attachment of our own expertise (whether design or analytic) to the computational process itself: if we start from a position oriented around computation, we run the risk of seeing only the problems that our solutions predispose us to address (per the old line, "when all you have is a hammer, all the world looks like a nail."). Other challenges attach to the kinds of partnerships we form with actors native to the fields we're working with. In few cases do HCI researchers wander into other fields in an unstructured way, without prior relations or specific points of entry with locally based actors. For their part, such actors are most likely to engage *us* for our perceived skills and contributions – technically-oriented HCI researchers for their tool-building capacities, social science-based HCI researchers for their perceived expertise around the organizational or governance challenges confronting new collaborative endeavors: to extend the hammer analogy, people who see nails are those most likely to hire carpenters. The result may be a highly partial picture or strategy for change that does not extend evenly across fields as a whole – a situation we may only become aware of later through forms of resistance, non-adoption, and workarounds to the programs of action we help to move forward. These considerations raise questions around the nature of HCI's *own* relations to field, and the conditions under which such engagements make ethical and practical sense. Which tie back in turn to deep and still evolving questions around the nature of HCI as a vocation.

CONCLUSION

The argument developed in this paper is simple in form (but complex in practice!): that senses of scientific vocation are grounded in distinct and historically layered object relations (including, for ecology, 'the field'); that new computational development *remediates* these relations, through processes of both loss and extension; and that efforts to develop new computational infrastructure for the sciences must take these dynamics into account. It is the result of these and other such encounters between technologically-mediated practice and traditions of value local to individual scientific fields – infrastructure and vocation – that will determine the shape, efficacy, and basic desirability of today's cyberinfrastructure and e-science investments.

ACKNOWLEDGMENTS

We wish to thank our many informants for their generosity, patience, and insight. This research is supported under U.S. National Science Foundation Grant #0847175.

REFERENCES

1. Canfield, M.R. *Field notes on science & nature*. Harvard University Press, Cambridge, MA, 2011.
2. Cummings, J.N. and Kiesler, S. Collaborative Research Across Disciplinary and Organizational Boundaries. *Social Studies of Science 35*, 5 (2005), 703–722.
3. Cummings, J.N. and Kiesler, S. Coordination costs and project outcomes in multi-university collaborations. *Research Policy 36*, 10 (2007), 1620–1634.
4. Dampier, W. *A new voyage around the world*. Printed for James Knapton, at the Crown in St. Paul's Church-yard, London, 1697.

5. Denning, T., Borning, A., Friedman, B., Gill, B., Kohno, T., and Maisel, W. Patients, Pacemakers, and Implantable Defibrillators: Human Values and Security for Wireless Implantable Medical Devices. ACM Press (2010), 917–926.
6. Duby, G. *Rural economy and country life in the medieval West*. University of South Carolina Press, Columbia, SC, 1968.
7. Durkheim, É. *The elementary forms of religious life*. Free Press, New York, 1995.
8. Forsythe, D.E. New Bottles, Old Wine: Hidden Cultural Assumptions in a Computerized Explanation System for Migraine Sufferers. *Medical Anthropology Quarterly 10*, 4 (1996), 551–574.
9. Fry, J. Coordination and Control of Research Practice Across Scientific Fields: Implications for a Differentiated E-Science. In C. Hine, ed., *New infrastructures for knowledge production: understanding E-science*. Information Science Publishing, London, 2006, 167–188.
10. Hey, A.J.G., Tansley, S., and Tolle, K.M. *The fourth paradigm: data-intensive scientific discovery*. Microsoft Research, Redmond, WA, 2009.
11. Hinds, P.J. and Kiesler, S., eds. *Distributed Work*. The MIT Press, Cambridge, MA, 2002.
12. Hine, C. Computerization Movements and Scientific Disciplines: The Reflexive Potential of New Technologies. In C. Hine, ed., *New infrastructures for knowledge production: understanding E-science*. Information Science Publishing, London, 2006, 26–47.
13. Jackson, S.J., Edwards, P.N., Bowker, G.C., and Knobel, C.P. Understanding Infrastructure: History, Heuristics, and Cyberinfrastructure Policy. *First Monday 12*, 6 (2007).
14. Jackson, S.J., Ribes, D., Buyuktur, A., and Bowker, G.C. Collaborative rhythm: temporal dissonance and alignment in collaborative scientific work. *Proc. CSCW 2011*, ACM Press (2011), 245–254.
15. Jirotka, M., Proctor, R., Hartswood, M., et al. Collaboration and Trust in Healthcare Innovation: The eDiaMoND Case Study. *Computer Supported Cooperative Work 14*, 4 (2005), 369–398.
16. Karasti, H., Baker, K., and Millerand, F. Infrastructure Time: Long-term Matters in Collaborative Development. *Computer Supported Cooperative Work 19*, 3 (2010), 377–415.
17. Knorr-Cetina, K. *Epistemic cultures: how the sciences make knowledge*. Harvard University Press, Cambridge, MA, 1999.
18. Kohler, R.E. *Landscapes & labscapes: exploring the lab-field border in biology*. University of Chicago Press, Chicago, 2002.
19. Livingstone, D.N. *Putting science in its place: geographies of scientific knowledge*. University of Chicago Press, Chicago, 2003.
20. Merton, R.K. Science and the Social Order. *Philosophy of Science 5*, 3 (1938), 321–337.
21. Merton, R.K. Science and technology in a democratic order. *Journal of legal and political sociology 1*, (1942), 115–126.
22. Millerand, F. and Bowker, G.C. Metadata Standards: Trajectories and Enactment in the Life of an Ontology. In M. Lampland and S.L. Star, eds., *Standards and their stories: how quantifying, classifying, and formalizing practices shape everyday life*. Cornell University Press, Ithaca, NY, 2009.
23. National Science Foundation Cyberinfrastructure Council. Cyberinfrastructure Vision for 21st Century Discovery. 2007. http://www.nsf.gov/pubs/2007/nsf0728/nsf0728.pdf.
24. Olson, G.M. and Olson, J.S. Distance matters. *Human-Computer Interaction 15*, 2 (2000), 139–178.
25. Ribes, D. and Finholt, T. The Long Now of Technology Infrastructure: Articulating Tensions in Development. *Journal of the Association for Information Systems 10*, 5 (2009).
26. Shapin, S. *The scientific life: a moral history of a late modern vocation*. University of Chicago Press, Chicago, IL, 2008.
27. Shapin, S. *Never pure: historical studies of science as if it was produced by people with bodies, situated in time, space, culture, and society, and struggling for credibility and authority*. Johns Hopkins University Press, Baltimore, MD, 2010.
28. St. Augustine. *The City of God*. Modern Library, New York, 1950.
29. Star, S.L. and Ruhleder, K. Steps Toward an Ecology of Infrastructure: Design and Access for Large Information Spaces. *Information Systems Research 7*, 1 (1996), 111–134.
30. Weber, M. *The vocation lectures: science as a vocation, politics as a vocation*. Hackett Publishing Company, Indianapolis, IN, 2004.
31. White, G. *The natural history and antiquities of Selborne*. T. Bensley, London, 1789.