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Fieldwork in landscape ecology

Jesse E.D. Miller, Carly D. Ziter, and Michael J. Koontz

Introduction

Landscape ecology explores the biological and societal causes and consequences of landscape heterogeneity. Landscape ecologists often seek to synthesize patterns and processes across multiple spatial scales, and fieldwork is an indispensable and central technique for accomplishing this. Here, we define fieldwork as personal, in situ observations of biological and societal patterns. Fieldwork and data from other sources, such as remotely sensed landscape imagery, often play complementary roles in landscape ecology research. For example, fieldwork allows the relatively precise quantification of biological and social patterns and processes at typically fine spatial scales, while remotely sensed data facilitates often coarser quantifications of landscape variables across broad spatial extents. Fieldwork has remained a critical component of much of landscape ecology research for decades because it continues to provide unique information, despite rapid advances in technology for characterizing ecological patterns and processes.

Fieldwork plays several roles in landscape ecology research. Perhaps most prominently, fieldwork is used to characterize biological or social patterns and processes so that they can be related to landscape context. Fieldwork is also frequently used to field-calibrate remotely sensed data, such as landscape imagery and sensor data. While these two roles often involve different methods, they both typically attempt to capture data at a finer scale than remotely sensed imagery can provide and often make types of measurements that are outside the capabilities of remote sensing. In one example of relating field measurements of biological patterns to landscape variables, researchers explored the role of landscape context in plant community restoration project outcomes (Grman et al. 2013). A large body of field research has also explored the influence of landscape spatial configuration on plant community diversity and functional traits (e.g., Marini et al. 2012, Auffret et al. 2016, Miller et al. 2018). Other examples of influential field studies in landscape ecology include research showing that forest fragmentation can influence host–parasitoid relationships (Roland and Taylor 1997) and research estimating the effects of wildfire on nutrient cycling (Walker et al. 2018).

In experimental landscape ecology, fieldwork may also involve manipulating landscapes either in microcosms or at broad spatial scales. One large, landscape-scale manipulative experiment, the Corridor Project, has been used to show that habitat connectivity affects numerous taxonomic groups, such as plants (Damschen et al. 2006), butterflies (Haddad and Baum 1999), and arthropods (Orrock et al. 2011). Fieldwork is also sometimes used to quantify landscape patterns themselves, especially for fine-scale landscapes; researchers in Newfoundland have used landscape ecology methods to explore the dynamics of lichen patches on tree trunks as micro-landscapes (Wiersma et al. 2019). Contemporary landscape ecology fieldwork may also involve deploying drones (discussed further later) or other sensors (Chapter 13) in the field to create customized landscape imagery and other data.

The broad spatial extent at which many landscape ecology studies operate leads to conceptual and logistical challenges that differ from those faced in locally focused work. Because landscape studies often focus on large study regions, fieldwork can involve significant travel, and individual studies may span multiple land ownership boundaries and major geographical gradients. Establishing sufficient independent landscape replicates for inference while avoiding pseudoreplication is another frequent challenge in landscape ecology study design. The successful navigation of such challenges, however, can lead to broad and meaningful insights into natural and social patterns. Indeed, when well designed, field-based landscape ecology research can develop inference that combines the depth of field-based natural history expertise and the breath that contemporary technological approaches (e.g., remote sensing and other big data) can confer.

Fieldwork and the development of landscape ecology

Fieldwork has played a substantial role in the development of landscape ecology, and many of the early foundational papers of the nascent discipline half a century ago made extensive use of fieldwork. In one influential field study, Wright (1974) used pollen deposition and tree ring analyses to show that fire should be used as a management tool, a then-controversial perspective in many circles of forest ecologists that has since entered the mainstream. Wiens (1976) drew on hundreds of field-based studies in his foundational review of population responses to patchy environments, which highlights the importance of scale in the relationship between species and their environment. Bormann et al. (1968) conducted one of the first landscape-scale vegetation manipulation experiments, demonstrating that timber harvest can cause large-scale nitrogen loss from ecosystems.

A diversity of techniques and approaches are needed to address the mounting global challenges that ecologists face in the contemporary era of unprecedented global change. As technological advances yield novel tools for inference in ecology, such as greatly expanded remote sensing capabilities and advances in modeling and computational approaches, some ecologists have expressed concern that fieldwork and natural history may be falling by the wayside (Ríos-Saldaña et al. 2018), and empirical landscape ecology studies in the United Kingdom are believed to have declined recently (Young et al. 2019). One common concern is that ecologists who lack field-based experience and natural history skills may not be able to meaningfully interpret 'big data' sets that they were not personally involved in collecting. We agree that fieldwork and natural history continue to be a critical tool for the advancement of landscape ecology, but we also recognize that these approaches are often complemented by non-field-based approaches. When done well, fieldwork and non-field-based approaches can be mutually reinforcing.

Best practices in landscape ecology fieldwork

Independence is often described as the most important assumption of parametric statistics. As the first rule of geography establishes, things that are spatially closer together tend to be more similar, and this may be true of landscape variables of interest, such as environmental, biological, or socioeconomic variables. Samples that are independent are not correlated, in the sense that a given observation of a variable does not depend on values of other observations as a function of time or space. The term *pseudoreplication* refers to non-independent samples being treated as independent for purposes of analysis. Designing landscape ecology studies while avoiding pseudoreplication can be challenging given the broad scale at which landscape ecology studies are often conducted. Establishing independent landscape replicates (i.e., multiple study landscapes that do not overlap or that overlap only minimally) is important in many landscape ecology studies but may require large study regions with well-dispersed study sites.

For landscape ecology studies to be meaningful, they must span substantial variation in predictor variables of interest (Eigenbrod et al. 2011). This is especially important for detecting non-linear patterns, such as a saturating relationship between variables, where no relationship will be detected if only part of the range of the predictor variable is sampled. Landscape ecology studies must also carefully consider the grain and extent at which research is conducted, since ecological relationships may be scale-dependent (Chapter 3). In one example of scale-dependence, Fricker et al. (2019) found that topography became an increasingly important driver of tree height relative to climate at finer scales.

Thoughtful study design is an essential precursor to successful landscape field studies. Developing specific research questions and goals is an important first step in designing a field study, since it is difficult to choose an appropriate sampling strategy when the research goals are vague (Sutherland 2006). Once goals are defined, a specific sampling protocol can be established; sampling should occur at a scale that will capture heterogeneity in variables of interest. Study plots, sometimes with nested quadrats, are often used to measure community diversity or estimate species abundance. Linear transects or belt transects, along which data are collected periodically at points or nested quadrats, are another approach that may be especially useful in landscapes characterized by clinal or hierarchical environmental heterogeneity (Sutherland 2006). Another important consideration in study design is the tradeoff between sampling effort at each plot and the total number of plots in the study; in general, replicating at the highest level (e.g., collecting samples from more sites with less intensive effort per site) will produce the best results (Karban and Huntzinger 2006).

Choosing sampling locations within study regions is another important consideration. Randomly locating plots or transects is often considered an ideal approach, though there can also be advantages to using an evenly spaced sampling layout (e.g., grid designs; Elzinga et al. 1998, Sutherland 2006). Subjectively selecting 'representative' study locations or arbitrarily choosing sampling locations in the field may lead to bias in site selection and should be avoided (Sutherland 2006). Stratified random sampling may be a useful approach in heterogeneous landscapes that can be blocked into multiple discrete categories based on ecological differences or other factors such as site accessibility. Under a stratified random sampling scheme, a predetermined number of sampling locations are randomly chosen within two or more discrete regions of the study area; this can be useful when the abundance of habitats or organisms of interest varies substantially between regions or when different regions cannot be sampled with equal intensity.

Designing studies that accurately capture variables of interest while avoiding bias and meeting the requirements of independence may be very challenging at times, especially in systems where potential study sites are limited. However, advance planning can help ameliorate these challenges. Carefully examining maps or landscape imagery and scouting potential field sites can help researchers anticipate and control for unexpected complications such as confounding variables. Conducting small pilot studies may also help researchers identify potential problems such as correlated predictor variables before a great deal of time and resources have been invested in study sites that may lead to problematic data sets. Finally, researchers should also keep in mind that no field study is perfect, and the guidelines we mention here are not absolute. For example, small amounts of overlap (e.g., pseudoreplication) in study landscapes may pose minimal problems for inference (Eigenbrod et al. 2011).

The logistical challenges of sampling study sites across large study regions can be substantial. Significant amounts of travel time are often required for a single researcher or team to conduct such studies, which may reduce time for actual sampling. Establishing networks of researchers who follow similar protocols at widely dispersed study sites or regions can be one effective approach to this challenge. Some examples of such networks in North America include the Long Term Ecological Research Network, the Nutrient Network, the National Phenology Network, the National Ecological Observatory Network, and the Global Observation Research Initiative in Alpine Environments (GLORIA). Similarly, collaborations with community members and tools such as iNaturalist can be useful in landscape ecology (see further discussion of community-based science later).

Adapting fieldwork to different socioeconomic contexts

Landscape ecology fieldwork takes place in landscapes that can be geographically and socially diverse. Navigating this heterogeneity is generally easiest when researchers conduct careful advance planning but also maintain an adaptable and flexible attitude. Perhaps the only universal rule of fieldwork is that it rarely goes exactly as planned. As experienced fieldworkers, we have learned to accept and even sometimes enjoy some of the unexpected occurrences that seem to characterize fieldwork, which can range from a down tree blocking a road to encounters with community members. An important first step in embarking on any field project is planning in advance for anticipated logistical and safety concerns, which vary with the geographic context of studies, as we describe later.

As scientists and fieldworkers, we may be outsiders to some extent, working in areas where we do not live (even if we have come to know them well). As such, we are guests in landscapes where other people live and work, and sensitivity to the needs and concerns of local communities and other stakeholders is important. Led primarily by our colleagues in the social sciences and humanities (e.g., human geographers, political economists, and historians of science), there has been growing recognition of the need for anti-colonial, feminist, or 'decolonized' methods of conducting research that meaningfully engage with local communities and value traditional ecological knowledge (e.g., the Civic Laboratory for Environmental Action Research; https://civiclaboratory.nl/). Regardless of our specific study system or location, it is critical that ecologists examine the ways in which our research agendas and fieldwork practices may relate to or reinforce inequalities in the areas in which we work (Baker et al. 2019). In this spirit, we (the authors of this chapter) acknowledge that our perspective and fieldwork experience are biased to that of researchers from the Global North (North America) conducting fieldwork within this region.

One way in which researchers have engaged with local communities in their study areas is through the co-production of research, where scientists actively partner with the people affected by the research to shape how projects are conceived, supported, conducted, and disseminated (Hickey et al. 2018). While this is a challenging and often time-consuming process when done in an intentional and meaningful way, it can lead to outcomes that are better aligned with the values and needs of society. In the United States, one productive boundary-spanning organization is the U.S. Forest Service Regional Ecology Program, which facilitates collaborations between academic researchers and government agency land managers to address critical management challenges (Safford et al. 2017). In Canada, collaborative research between academics and Indigenous communities has led to more effective conservation plans for both communities and scientists; for example, combined use of genetic analysis of caribou scat and place-based traditional knowledge has broadened understanding of caribou population dynamics in northern landscapes (Polfus et al. 2016).

Even when not engaging fully in a co-production model, fieldwork typically requires receiving permission from third parties to access study sites. Landscape ecology fieldwork in particular often involves establishing study sites across political and/or land ownership boundaries due to the need to capture broad extents and spatial heterogeneity. Practically, this often means that permits must be obtained from multiple land managers, such as government agencies, non-government organizations, or private landowners. In the United States, numerous government agencies control vast land holdings, and it is our experience that agencies vary substantially in their approaches towards permitting researchers. Some agencies have very straightforward application processes and issue permits quickly, while others require labyrinthine processes to receive a permit even for benign activities such as observational studies. In the latter cases, one thing we have learned is that identifying and contacting the person who ultimately processes research applications is often the surest way to accelerate the process of permit approval, especially when permit applications are submitted via an opaque online portal. One of us once had a permit application stagnate unapproved for over a year until we determined who to contact to ask for assistance, after which it was approved within days. In our experience, individual agency personnel are often friendly and interested in providing assistance with navigating what can be complex bureaucratic processes.

In contrast to working with agencies, gaining permission to access private land may require a less formal approach. We have found (in North America) that the easiest method is typically to contact the landowner or manager directly with a request. In the case of businesses or corporate landowners, researchers may be directed to a permit process. However, in the case of individual landowners (e.g., farmers or homeowners), it is often sufficient to establish permission directly either over the phone, by email, or in person. In this case, the most difficult part of the process is often establishing initial contact. It is important to leave adequate time to navigate this process, as it is not uncommon for studies to require permission from numerous individual landowners in heterogeneous landscapes; e.g., in agricultural, ex-urban, or urban areas. Once permission has been granted, maintaining communication with property owners for the duration of the research can be important for a successful field season and can leave the door open to future research collaborations (Hilty and Merenlender 2003, Dyson et al. 2019).

In some cases, researchers may also choose not to request permits for research even when they may technically be required. For example, one colleague of ours successfully completed a large observational study that took place mostly along roadsides where the agency that controlled rights-of-way was uninterested in facilitating research. However, penalties for conducting illegal research are extremely severe in some parts of the world, and we advise that researchers comply with local laws. When beginning any new project, it is important to be aware of the local risks and repercussions that your presence and fieldwork presents and particularly, how these may differ across different governance contexts (e.g., public vs. private land). Communicating with other researchers or practitioners familiar with the social norms and legal obligations of the landscape of interest can be an informative step in fieldwork planning.

Urban fieldwork

Urban areas are complex mosaics of land covers characterized by different histories, vegetation, management, and climate (Cadenasso et al. 2007). This high spatial heterogeneity and frequent temporal change makes cities powerful systems for exploring landscape ecology questions. Given the differences in biodiversity, ecosystem structure, and function between urban ecosystems and their wildland counterparts, and the comparatively recent consideration of cities as ecosystems within mainstream ecology (Wu 2014), fieldwork still plays a fundamental role in understanding the ecological fabric of our cities. It is tempting to see urban fieldwork as an 'easy' option. Field sites are often close to home, and access to amenities throughout the field season (the lab, hardware stores, repair shops, etc.) can reduce some of the preparation stress compared with a wildland expedition. However, there are additional logistical challenges to contend with in an urban context that many classically trained ecologists have little experience of navigating (Dyson et al. 2019).

One of the most obvious differences in urban fieldwork is the extent to which human interactions pervade the work. The same heterogeneity that often makes urban areas attractive study regions also means that numerous different permissions may be required to access sites, for example. One author of this chapter recently conducted an urban study requiring permission from 70 different individuals (and field encounters with numerous additional individuals), which necessitated a substantial investment in relationship building and communication before, during, and after the field season (Ziter and Turner 2018). As in other fieldwork contexts, positionality (race, gender, sexual orientation, class) will influence the way a researcher is perceived by project partners and members of the local community. Speaking with someone familiar with the neighborhoods in which you hope to work, and forming relationships with community leaders, can be an important step in building trust within the community as well as offsetting safety concerns.

In addition to planning for extensive interactions with community members, research and sampling designs may also need to be adapted for working in a heavily human-dominated context. Modifying the timing of fieldwork activities to suit property owners or managers, adapting to frequent interruption, and reducing the impact of invasive sampling methods are all common experiences in urban areas (Dyson et al. 2019). Patterns of species occurrence and behavior may also differ in urban areas compared with nearby rural or natural habitat, such that natural history knowledge developed outside urban settings may be less reliable (Kowarik 2011, Johnson and Munshi-South 2017). As mentioned earlier, pilot studies can help to identify and address pitfalls in research design and make for an ultimately more successful field season.

Working landscapes and agroecosystems

Much of the earth's surface in temperate and tropical regions is used for agriculture and ranching, and a large body of landscape ecology research focuses on these ecosystems (Kremen and Merenlender 2018, Ellis 2019). Working in agroecosystems involves a unique set of considerations and challenges. There can be a tendency for people to distrust science and scientists in rural areas, and building trust can be key to working safely and efficiently. Co-production of research, as described earlier, can be useful to this end. Finding common ground with local people can also be useful. For example, in rural regions where local people may be skeptical of research on climate change, describing research in terms of tangible effects such as flooding may make the research more meaningful. We have also found that identifying as part of the agricultural college within our university – rather than the university as a whole – can help form a connection with community members. As previously mentioned, it is common for researchers' identity (e.g., race, gender, and sexual orientation) to influence how they are perceived in the field in rural areas as well. Keeping related safety concerns in mind is important, and researchers overseeing students or technicians should ensure that they are prepared and supported during fieldwork.

Rural residents, including land managers and farmers, are often some of the most knowledgeable people regarding the ecology of their lands. Engaging respectfully with local people can be a useful way for researchers to gain insight into their study systems and appreciate multiple ways of knowing. On the same note, we encourage researchers to be wary of the attitude that they are there to discover something 'new'. One component of engaging respectfully with local people includes planning research with awareness of land uses such as planting/harvest schedules, hunting, seasons, etc. It is important to recognize that your research will rarely take priority over people's livelihoods (nor should it). For researchers from urban areas in particular, developing awareness of local customs in rural places can be useful. One of us has worked in an isolated rural region where the pace of life is slow and local people commonly engage in conversation with anyone passing by (Miller et al. 2015); failing to recognize and participate in this friendly ritual could make it difficult to engage with and gain the trust of the local community.

Wildlands

Much landscape ecology research takes place in relatively wild landscapes outside urban and agricultural areas (e.g., Turner et al. 2010, Miller et al. 2015, Tingley et al. 2016). Working in wildlands typically involves fewer human encounters than work in human-inhabited areas, though those that do occur may be similar to those mentioned in the agroecosystems section. Maintaining inclusive and collegial work and living environments is another particularly important consideration for fieldwork in remote places; reports of harassment and assault in remote field environments are distressingly common (Clancy et al. 2014). Principal investigators and crew leaders should consider how they can develop policies and procedures to help create safe fieldwork environments for their teams.

Wilderness safety and being prepared for the isolation of remote places are important considerations for planning wildlands fieldwork. We have learned that it is good to be prepared for field trips to remote areas to last longer than planned. Extra food and water are important safety measures, since surprise changes of itinerary or weather are common during fieldwork, especially in remote places. While satellite navigation devices (e.g., geographic positioning systems) have made navigating in the back country easier, we always pack paper maps and compasses as well. Satellite communication devices can also add an extra layer of safety for areas where cell phone reception is unreliable. Accidents are most likely when researchers are tired or in a hurry, so we recommend working at a moderate pace and eating and sleeping well as accident prevention measures. Fieldwork will always carry some inherent risk, and conscientious management of that risk is the surest route to a successful field campaign.

Frontiers in landscape ecology fieldwork

Community-based science

Community-based science, also known as citizen science, is an approach to field data collection that is gaining traction among landscape ecologists. Community-based science generally involves many individuals or groups collecting data independently with varying degrees of central coordination. Such collaborative efforts to collect geographically disparate field data may succeed where they would prove impossible if undertaken by a single research group and can often be undertaken at minimal cost. Community-based science may take the form of professionally led efforts with participation from non-science professionals (e.g., bioblitzes, GLORIA), or decentralized, entirely non-professional efforts (e.g., eBird, iNaturalist). While they are manifold in form, the success of these community-based efforts for transforming landscape ecology research is fundamentally tied to a philosophy of open science: the idea that knowledge production should be reproducible, transparent, and accessible (Hampton et al. 2015, Bahlai et al. 2019). The benefits of crowd-sourced fieldwork are greatly reduced if collected data don't adhere to FAIR principles (data should be findable, accessible, interoperable, and reusable; Wilkinson et al. 2016). Data from community-based science may have more quality issues than data collected by professionals if data collectors are untrained. Nonetheless, the potential for the combination of community building and open science to revolutionize science as a whole is great, and landscape ecology stands to benefit in particular.

Drones

Advances in portability, accessibility, and capability of instrumentation have blurred the distinction between 'fieldwork' and 'remote sensing' approaches to landscape ecology. For instance, small unhumanned aerial systems (colloquially referred to as 'drones') can fit in a backpack, are inexpensive enough to be purchased on a small grant, are relatively easy to fly manually or on a pre-programmed flight path, and often come equipped with a capable camera. This makes them ideal tools for capturing fine-grain detail at relatively broad spatial extents. However, the range (i.e., flight distance) of these systems is limited by a need for a direct radio link to a ground-based controller, and thus, field visits are usually needed in order to use these tools. The dual identity of drone-based approaches (bridging fieldwork and remote sensing) adds some additional considerations for fieldwork, even if much of the data is collected from the air.

Drone-based approaches have an impact beyond the footprint of a strictly ground-based operation. This is a key strength of drones as a tool for ecology but also presents ethical challenges. For instance, Indigenous scientists and scientists engaged in knowledge co-production with Indigenous people may choose to use drone-based sampling as a means to preserve sovereignty and ensure data ownership (Martínez 2015, Haney 2016, Smith 2017, 'Decolonizing Digital: Empowering Indigeneity Through Data Sovereignty', 2019). On the other side of the coin, drone data (e.g., imagery) may extend beyond the area that is being intentionally surveyed, which may impose on the privacy of nearby people. Thus, special care should be employed when using drones to ensure that stakeholders have the agency to opt in or opt out of data collection depending on their needs. The extensive footprint of drones (e.g., the aircraft itself can be seen and heard from a distance) also requires consideration of wildlife beyond the area directly impacted by humans on the ground (Mulero-Pázmány et al. 2017). Based in part on these considerations, laws governing the use of drones abound in a global patchwork of regulatory frameworks (Stöcker et al. 2017). Because the rules regarding flights over wilderness, wildlife, and society are so variable in space and time, we suggest due diligence in learning the current relevant restrictions on the use of drones well in advance of fieldwork not only to ensure compliance with the law but also to avoid extralegal constraints. Beyond legal compliance, we also recommend exercising restraint and an abundance of caution when it comes to deploying these tools over areas that may cause harm or that may have their own influence on the very phenomenon being studied.

Other sensor technologies

Alongside developments in technology such as drones, other advanced sensors have also become more common in landscape ecology studies (Chapter 13). Further, the interconnectedness of sensors with each other and with the Internet (i.e., the 'Internet of Things') facilitates finely resolved, real-time ecological data collection at unprecedented scales (Guo et al. 2015, Bakker and Ritts 2018). One specific development in sensor-enabled fieldwork capitalizes on advances in sensor mobility. Recent studies have combined traditional fieldwork techniques such as environmental transects with mobile sensor technology (e.g., environmental sensors mounted on bicycles, cars, or boats) to collect fine-scale data on a range of environmental variables. Mobile sampling is a relatively affordable, efficient, and flexible way to capture fine-scale spatial data over large extents, and it is replicable over time. In urban landscapes, mobile sampling techniques have been used to investigate and map spatial patterns in air temperature (Ziter et al. 2019) and air pollution (Adams and Kanaroglou 2016). Mobile sampling has also been used in freshwater environments. For example, researchers in Wisconsin have developed 'FLAMe' (Fast Limnological Automated Measurements) technology to generate spatially explicit, real-time observations of surface water quality (Crawford et al. 2015, Loken et al. 2018). This approach has advanced 'landscape limnology' – the spatially explicit study of lakes, streams, and wetlands – a field now closely aligned with landscape ecology (Soranno et al. 2010).

Conclusion

Fieldwork has played a critical role in the development of landscape ecology, and it remains essential for addressing contemporary challenges such as understanding the landscape ecology of global change. Advances in technology have expanded the scope of fieldwork to include the deployment of drones and other sensors, and in recent years, researchers have expressed concerns that traditional fieldwork (e.g., organismal observation) may be declining. Continuing to train the next generation of researchers in field methods should be a priority for landscape ecologists. Indeed, there is great potential for combining fieldwork with modern sensor data and computational approaches to advance the field of landscape ecology.

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