# Landscape genetics

**Dr Helene H Wagner** discusses her aim to protect natural resources by overcoming the restrictions of ecological theories and methods, her work to improve conservation management and her vision for the future

**How would you explain the defining points of landscape genetics?**

Landscape genetics puts population genetics into real landscapes and addresses; for example, the effects of different landscape features, such as land-use types, on dispersal and gene flow across the landscape and its implications for genetic diversity and population viability. It also addresses the effects of landscape alteration and changing climate. Thus, from an evolutionary perspective, landscape genetics deals with environmental heterogeneity in space and time, and from an ecological perspective, it allows us to quantify and test hypotheses on how the landscape pattern affects the actual rates of exchange of individuals and their genes between remnant habitat patches.

**Are there limitations to existing ecological theories?**

Key examples are theories that deal with the spatial distribution of species (theory of island biogeography), individuals (metapopulation theory) or their genes (Wright's island models in population genetics). We want to apply these theories to the conservation of natural heritage in fragmented landscapes which keep changing due to socioeconomic drivers and climate change. This is problematic because classical theories may not consider, for example, the size or quality of remnant patches of natural or semi-natural habitat, the physical distance between them or the nature of the intervening landscape. Furthermore, these theories rely on equilibrium conditions, which are unlikely to be met in today's human-altered landscapes. Finally, statistical theory has similar limitations, so we often lack valid statistical methods to test our scientific hypotheses.

**Do you look predominantly at keystone species in your landscape studies, or does it require a more systematic approach?**

I'm fascinated by the dilemma that, while each species is different, landscape planning requires one-size-fits-all solutions. Typical solutions include focusing on umbrella, keystone or flagship species, or defining functional groups of species that are assumed to respond in similar ways. I favour a neutral approach, starting with the commonality among species and considering differences where necessary. For instance, we found that sheep effectively transport seeds of many species between pastures, not only those classified as being dispersed by animals, though those with appendages that facilitate adhesion to the fleece may be transported in larger numbers.

**What interactions have you observed over the course of this project? How will this be used to develop a more holistic means of conservation?**

We have learnt that seed dispersal by sheep can play a substantial role in helping plant species recolonise patches after local extinction, rescuing small populations from extinction and maintaining gene flow among local populations, which may help prevent inbreeding effects and maintain potential for adaptation to changing environmental conditions. This applies to a wide range of plant species, not only those with morphological seed adaptation to dispersal by animals, though there remained a group of species that did not respond to increased connectivity by shepherding. These species will require special attention. Our research results are used by local and regional conservation authorities to improve conservation management and support policy development.

**In recent years, connectivity has become a hot topic for conservationists. On a planet with increasingly smaller wild spaces and far more fragmented ecosystems, how do you propose further damage is halted?**

In addition to ecological compensation, the key lies in landscape-scale natural heritage system planning as a political mandate, ie. a legal requirement combined with a culture of scientific planning, evaluation and adaptive management of natural heritage systems. It is difficult to conduct controlled experiments at these spatial and temporal scales, and the scientific basis is still limited and biased towards birds and mammals. On the other hand, development restrictions and mitigation measures, such as culverts or green bridges, are costly and may be contested in court, where solid scientific justification is required.

**Finally, what is your ultimate goal?**

My vision is to bring together scientists with different backgrounds, personalities and skills who share a passion for scientific discovery through the novel combination of concepts and approaches from disparate fields to address scientific challenges that result from ecological problems relating to climate change and human landscape alteration.

Ecological theory and methods largely rely on assumptions that are inadequate to address the complexity of the real world. What is ultimately required is a spatial theory of biodiversity (of neutral genetic variation, adaptive variation and species) that predicts the interaction among key processes and the system behaviour during phases of transition, the testing of this theory in real systems and its application towards effective conservation in a changing world.

# Staying connected

**Researchers at the University of Toronto, Canada, are conducting pioneering studies in the interdisciplinary field of landscape genetics. Their findings of how human changes to landscapes are affecting ecosystems, advancing ecological knowledge and informing policy**

**HUMAN LANDSCAPE ALTERATION**, in combination with climate change, poses a serious threat to biodiversity. Yet, the ability to sustainably manage resources and preserve natural heritage within these lands first requires acute understanding of the dynamic, fundamental role landscape-wide interactions have on smaller scale ecological and genetic processes; knowledge that has so far been limited.

Professor Helene H Wagner's spatial ecology and landscape genetics laboratory at University of Toronto Mississauga is applying a novel approach to garner evidence on how environmental factors affect organism movement behaviour. By harnessing the power of molecular genetics to study dispersal processes that are otherwise invisible at a landscape scale, they aim to surmount the limitations of existing ecological theories and statistical models and provide innovative tools to tackle present and imminent challenges in conservation.

## THE CONSEQUENCES OF DISTURBANCE

Landscape genetics is one of the most exciting fields to have emerged from biology in the past two decades. It arose out of the concern of habitat fragmentation and need to reconnect patchy land, and at a time when the Millennium Ecosystem Assessment was being digested and widely discussed. Indeed, within the pages of the prestigious Assessment, it notes that 'more land was converted to cropland in the 30 years after 1950 than in the 150 years between 1700 and 1850'. Change has been rapid. Not only have physical scars left their mark as landscapes have been altered, but physical and biotic processes have been disrupted as formerly widespread natural habitat has been reduced to small and often isolated remnant patches (habitat fragmentation).

In a patchy landscape, there is increased risk of local extinction from abiotic and biotic disturbance and less chance of patch recolonisation by immigrants. Climate change and biological invasions may put populations at further risk and challenge species' abilities to adapt their geographical range and respond to environmental conditions or competitive interactions. Climate change may be the most prominent threat to biodiversity, but the often undisclosed consequences of habitat loss represent the largest direct cost, and the interactive effects of climate change and habitat loss are little understood.

## COLONISE AND CONQUER

Landscape connectivity has two elements; the first is concerned with the spatial arrangement of landscape features (structural connectivity) while the second (functional connectivity) describes the exchange of individuals and their genes among patches. If this function is disturbed, then local extinction may not be effectively counteracted by immigration. Gene flow, essential for maintaining a healthy, genetically diverse population, may be severed, which may lead to problems of inbreeding and reduce the ability to adapt in response to environmental change.

## WORKING TOGETHER

Although structural connectivity is relatively easy to map from existing geospatial data, scientists require additional information to test the effect of landscape features, such as roads and different land-use types, on functional connectivity, ie. dispersal and resulting gene flow. While GPS technology provides large-scale movement data for mammals, the dispersal of many other species, including plants, across a landscape can only be inferred indirectly from molecular genetic data. As this approach requires the integration of concepts from multiple disciplines, Wagner's research is inherently collaborative. "Landscape genetics is an amalgamation of landscape ecology, population genetics and spatial statistics, and true progress in this area can only happen if we integrate these fields," she explains. Importantly, the field injects fresh ideas into conservation and the minds of budding scientists. As part of the web-based Distributed Graduate Seminar in Landscape Genetics, Wagner also collaborates to train the next generation of scientists across six continents and conduct research that narrows the divide between previously isolated scientific domains.

## A NATURAL EXPERIMENT

What makes this work so important is that although governments and conservation agencies invest heavily to maintain and restore landscape connectivity through the planning of natural heritage systems, the effectiveness of such projects is rarely assessed. Wagner and her team therefore evaluated the success, or failure, of an ecological of network of calcareous grassland established around 25 years ago near Weissenburg, Bavaria, Germany.

**Participant locations for the distributed graduate seminar.**

CALCAREOUS GRASSLANDS are species rich ecosystems, with high conservation value, but they have suffered huge habitat loss and fragmentation in the past century. The decline of traditional management methods (either through conversion to cropland or the abandonment of grazing by sheep, cattle or horses, and the consequent succession towards forest) has led to up to a 90 per cent loss in habitat and dramatic species decline within the remaining fragments.

The study was based upon an extensive baseline survey taken in 1989, prior to the establishment of an ecological network which reconnected previously abandoned grassland patches with existing grazed pastures through rotational shepherding. A repetition of the survey in 2009 revealed that the richness of habitat specialist plants increased in the patches reconnected by shepherding compared to unconnected patches, as did colonisation rates. Species-level analysis indicated that rotational shepherding may have been the primary driver of functional connectivity for most characteristic calcareous grassland plants, even those without dispersal adaptations, thus corroborating the ecological relevance of earlier experimental findings that many different types of seeds may be transported in the fleece of sheep. Wagner now hopes to conduct a more detailed analysis of species groups to assess the risk factors for extinction.

The species distribution data were combined with genetic data from three plant species in the area, providing a unique opportunity to assess the degree, spatial scale and landscape determinants of functional connectivity by seed dispersal in herbaceous plants. Paternity analysis, using molecular genetic markers to identify the fathers or pollen donors of seeds collected from known mother plants in the field, will help understand how important the dispersal of pollen and seeds are, respectively, for maintaining gene flow among grassland patches. With computer simulations, these results can be generalised to other landscapes to assess landscape determinants of seed dispersal and pollen flow.

Wagner's findings from the Weissenburg 'natural experiment' provide sorely needed evidence for the importance of connectivity by seed dispersal amongst fragmented plant communities and support for the role of shepherding in restoring functional connectivity in this system. More generally, her group has demonstrated the importance of establishing baseline data and including principles of experimental design where possible before investing in landscape connectivity projects. This evidence will be useful both to justify funding and to assess the effectiveness of projects, thereby informing both science and policy.

## ACCOUNTING FOR COMPLEXITY

The focus on pressing conservation challenges in today's constantly altering landscapes reveals that existing theories on biodiversity, population ecology and population genetics make a number of assumptions which, as the landscape changes, are defied. For example, theories often assume that the amount, quality and connectivity of habitats remain constant over time. By studying the effects of these violations, both conceptually and empirically, Wagner is able to make ecological theory more applicable to the challenges of conservation in human-altered landscapes. Simultaneously, novel analytical tools are needed that can handle the complexity of landscape genetic data. Such tools are hard to come by, but Wagner and her colleagues are ahead of the game, and already in the process of devising methods for the statistical modelling of spatial processes in ecological and landscape genetic data.

## IMPLICATIONS FOR CONSERVATION

Wagner has already provided robust scientific evidence to support ecological policy development in Germany and is now planning to develop research projects in the Greater Toronto Area, in collaboration with regional conservation authorities and the Ontario Ministry of Natural Resources. She continues to refine existing theories and innovate analytical tools, and in doing so will make them more relevant to human-altered environments. Ultimately, this research could provide the evidence-base to protect genetic diversity and safeguard species in heterogeneous landscapes through maintaining the ecological and genetic processes that promote the persistence of viable populations.

## INTELLIGENCE

### SPATIAL ECOLOGY AND LANDSCAPE GENETICS LABORATORY

### OBJECTIVES

**Spatial ecology** – to identify processes shaping population and community dynamics by assessment of spatial and temporal patterns

**Metacommunity dynamics** – to assess connectivity among ecological communities and associate patterns of species diversity with landscape patterns

**Landscape genetics** – to test hypotheses on which landscape features critically affect dispersal and gene flow

### KEY COLLABORATORS

**Dr Marie-Josée Fortin**, University of Toronto • **Dr Rolf Holderegger**, Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Switzerland • **Dr Hans Jürgen Böhmer**, Technical University of Munich, Germany


### FUNDING

Natural Sciences and Engineering Research Council of Canada (NSERC)

University of Toronto Connaught Fund

Regierung von Mittelfranken


### CONTACT


**Dr Helene H Wagner**
Associate Professor

University of Toronto Mississauga
3359 Mississauga Road
Mississauga, Ontario
L5L 1C6
Canada

**T** +1 905 569 4702
**E** helene.wagner@utoronto.ca

**www.utm.utoronto.ca/~wagnerh1**


**HELENE H WAGNER** is Associate Professor at the Department of Biology, University of Toronto Mississauga and the Department of Ecology and Evolutionary Biology, University of Toronto, as well as Associate Faculty in the School of the Environment, University of Toronto. As a landscape ecologist, she is interested in understanding how human landscape alteration affects biodiversity patterns and processes. Ecological theories relating to biodiversity rely on assumptions on equilibrium conditions and dispersal that are often unrealistic in spatially heterogeneous and changing human altered landscapes. To determine how landscape affects biodiversity patterns and processes and derive implications for conservation and natural resource management, the research in her lab falls into three broad, complementary topics: spatial ecology, metacommunity dynamics, and landscape genetics. Depending on the research question, Wagner combines field experiments, surveys of natural populations and communities and computer simulation, using a broad range of methods including spatial and multivariate statistics, GIS, molecular genetics, soil analysis and spatiotemporal dynamic modelling.

UNIVERSITY OF TORONTO