

trends, main habitats, major threats and conservation measures, both those already in place and those that are still needed.

*Threatened Birds of the World*⁴, the most recent publication in the series of books edited by BirdLife International was officially launched at the meeting. In this update of the assessment made in 1994, the number of threatened birds is estimated to have increased by 12% in just six years⁵. Two forest species of honey eaters of Hawaii are now officially considered to be extinct, while 14 more species are listed as critical and 86 more are considered endangered. In contrast to previous assessments, the book also identifies practical actions required to decrease extinction risk, and defines specific conservation targets aimed at reducing the number of threatened bird species by 10% by the year 2005.

The third initiative, the SIS is a major effort of the Species Survival Commission (SSC) of IUCN, a volunteer network of over 7000 scientists and conservation practitioners from almost every country in the world. The SSC is the main source of scientific and management expertise for IUCN at the species level, and a key player in generating the data on which threatened species lists are based. The SIS was created in response to the growing number of conservation initiatives occurring at local, national and regional levels, which require up-to-date information on the status of taxa at these geographical scales. SIS is a decentralized

network of interlinked databases, which will eventually be available remotely to anyone with Internet access. In addition to providing direct access to the wealth of information generated by SSC specialist groups, the SIS will also offer an updated reference on taxonomy, as well as an in-built capability for assigning red list categories to species on the basis of their population trends, demography or geographical distribution⁶.

Finally, delegates participated in 12 'interactive sessions', a set of one-day symposia that presented current thinking and trends on a variety of topics relevant to the 'ecospaces' theme of the congress. The emphasis on 'ecospaces' recognizes that transboundary management of ecosystems is a necessary underlying principle of any successful effort for biodiversity conservation. National and state or provincial borders often do not follow natural boundaries, such as watersheds, oceans and mountain ranges, thus demanding joint stewardship among neighbors who occupy these human-made divisions of the landscape.

The Amman congress successfully brought together and provided a forum for exchange among the main players of the largest conservation organization of the world. However, successful achievement of the mission of IUCN will require reversing current trends in the way that humans interact with the rest of the world. As reflected in the words of IUCN Director General Maritta von Bieberstein Koch-Weser, the organization is ready for

the task: 'We have the knowledge, technology and human resources to avert the extinction crisis. What is missing is the political commitment to use them and to invest in them in the interest of future generations. No loss of species is acceptable to IUCN – no species should go extinct.' A successful integration of science and policy is therefore the challenge for future WCCs to meet.

Acknowledgements

Together with S. Andelman and D. Boersma, I attended the WCC as a representative of the Society for Conservation Biology. I am grateful to K.M. Rodríguez-Clark for comments on this report.

References

- 1 Robinson, J.G. *et al.* (1999) Wildlife harvest in logged tropical forests. *Science* 284, 595–596
- 2 Bennett, E.L. (2000) Timber certification: Where is the voice of the biologist? *Conserv. Biol.* 14, 921–923
- 3 Hilton-Taylor, C. (compiler) (2000) *2000 IUCN Red List of Threatened Species*, The World Conservation Union
- 4 Birdlife International (2000) *Threatened Birds of the World*, Lynx Editions
- 5 Collar, N.J. *et al.* (1994) *Birds to Watch 2. The World List of Threatened Birds*, BirdLife International
- 6 IUCN (1994) *IUCN Red List Categories*, The World Conservation Union Species Survival Commission

Jon Paul Rodríguez

Centro de Ecología, Instituto Venezolano de Investigaciones Científicas (IVIC), Apartado 21827, Caracas 1020-A, Venezuela.
e-mail: jon@eno.princeton.edu

Ecological boundaries: a search for synthesis

William F. Laurance, Raphael K. Didham and Mary E. Power

The workshop on Structure and Function of Boundaries in Ecological Mosaics was held at the Institute of Ecosystem Studies, Millbrook, New York, USA, from 17 to 19 October 2000.

Boundaries are ubiquitous in nature. From cell membranes to soil–air interfaces to the abrupt margins of forest fragments, they define transition zones that separate distinctive entities. In the heterogeneous natural world, many boundaries act like simple semi-permeable membranes, allowing certain substances to flow freely while inhibiting others – forest edges, for

example, can be permeable to habitat-generalist species but can halt forest specialists. Other boundaries act as more than just a physical filter, transforming both the quantity and quality of fluxes across their interface – the intertidal zone, for example, supports a unique biota that is not simply intermediate between that of the land and sea.

Despite the extraordinary structural and functional diversity of ecological boundaries, researchers in vastly different fields are asking similar questions about the roles of boundaries in their systems. Is it possible that such boundaries are governed

by a common set of physical and biological processes? If so, a kind of synthesis might be possible, in which universal principles of boundary function are postulated, tested and defined. Such a synthesis would be invaluable, as it is becoming apparent that, at a variety of spatial and temporal scales, natural systems are actually mosaics of distinctive patches that are delimited and maintained by various kinds of boundaries.

This quest for synthesis was the focus of this recent workshop entitled 'Structure and Function of Boundaries in Ecological Mosaics', which brought together about three dozen ecologists from widely

disparate fields to grapple with boundary concepts. The main goals of the workshop, as outlined by ecologists Mary Cadenasso, Steward Pickett and Kathleen Weathers from the Institute of Ecosystem Studies (Millbrook, New York, NY, USA), were to synthesize our current knowledge about ecological boundaries and then to develop new priorities and integrated research themes.

The workshop was launched with a series of talks that illustrated just how diverse and important boundaries are in nature. Tracy Benning (University of California, Berkeley, CA, USA) provided an historical overview of vegetation-boundary research, from its genesis early in the last century with the classical ecotone concept of Frederick Clements, to its wide application in the next few decades by wildlife managers, who viewed habitat edges as being beneficial for game species. A far less benign view of edges has emerged more recently, showing that the abrupt, artificial margins of habitat fragments have deleterious effects on many nongame species and natural ecological processes.

Other speakers provided eye-opening examples of boundaries in other systems. Susan Bell (University of South Florida, Tampa, FL, USA) described how coral-reef fish often form a 'wall of mouths', creating halos around reef margins where zooplankton and seagrasses are depleted. This clearly demonstrates that boundaries are sometimes functional rather than structural in nature. At much smaller spatial scales, Mary Firestone (University of California, Berkeley) argued that the rhizosphere layer around plant roots, and even the interfaces between soil aggregates and surrounding interstitial spaces, are extremely active biologically and chemically, but that the importance of these boundary layers remains poorly understood. Finally, Marie-Josée Fortin (Simon Fraser University, Burnaby, BC, Canada) highlighted the importance of quantitative statistical methods for detecting nonrandom fluxes across ecological boundaries.

The heart of the workshop was a series of small-group discussions, focused on integrating boundary concepts and research, with each group reporting their conclusions in plenary sessions. Many groups struggled initially, with discussions bogged down by semantic, sometimes pedantic debates about terms and definitions. Discussions were also plagued

Box 1. Examples of null hypotheses of boundary function based on simple physical, geometric and biological principles

Hypothesis	Underlying principles
(1) When adjoining patches differ in productivity, there will be a net flux of energy from the higher- to the lower-productivity patch	Mass Effect; Second Law of Thermodynamics
(2) As the degree of contrast between adjoining patches increases, biological flows (e.g. inter-patch movement of organisms) will decline while physical flows increase	Habitat specialization; Diffusion
(3) Boundary characteristics will often vary systematically and predictably with boundary age	Vegetation succession
(4) In heterogeneous mosaics, differences among patches will tend to decline over time for patches that are small or irregularly shaped, or when boundaries are more permeable or more dynamic in space or time	Small or irregular patches have high edge:area ratios; High edge turnover or permeability increases flux rates

by the lack of a clear framework and mechanistic models for understanding boundary function, and by profound differences among researchers in the nature and spatial scales of the phenomena studied.

Eventually, however, real insights did begin to appear. One working group produced a very useful 'Taxonomy of Boundary Types' that helped categorize boundaries based on their structural and functional characteristics. Another group proposed a 'General Theory of Ecological Boundaries' based on hypotheses and predictions that can be generated using simple biological, geometric and physical principles (Box 1). Although biological systems are obviously complex and multifactorial, basic mechanistic models can sometimes provide a surprisingly good approximation of boundary function; for example, Florence Thomas (University of South Florida) found that a simple fluid-dynamics model could be used effectively to predict the relative rates of ammonium uptake by coral reefs with varying surface textures.

A number of research priorities emerged from the workshop. First, physical boundary models can serve as useful null hypotheses (Box 1) – deviations of ecological boundary dynamics from predictions point to the consequences of biology or ecology at the edge. Second, experiments can provide important insights into boundary function; for example, manipulations of deciduous-forest edges by IES scientists clearly showed that edge structure has a major impact on seed dispersal and seedling predation. Third, cross-scale studies are needed to determine whether boundary phenomena are scale-dependent. Fourth, multidisciplinary studies of a single model system, such as a fragmented landscape, are

needed to assess whether different kinds of boundary phenomena respond similarly to various sets of conditions. Finally, understanding how the characteristics of individual boundaries change over time will improve our ability to predict the consequences of such changes in nature.

Although much remains to be done, it is apparent that there is great scope to integrate studies of many different kinds of ecological boundaries, and to develop new models that can better predict boundary functioning. Such studies have many practical applications. For example, William Fagan (Arizona State University, Phoenix, AZ, USA) and his colleagues are developing theoretical models to determine whether wildlife populations can persist in isolated nature reserves with varying degrees of edge hostility. Such studies will help scientists better understand and conserve nature in an increasingly edgy world.

Acknowledgements

We thank Mary Cadenasso and Kathleen Weathers for commenting on this report. Support for the workshop was kindly provided to IES by the A. W. Mellon Foundation.

William F. Laurance*

Smithsonian Tropical Research Institute, Apartado 2072, Balboa, Republic of Panamá.
*e-mail: wfl@inpa.gov.br

Raphael K. Didham

Department of Zoology, University of Canterbury, Private Bag 4800, Christchurch, New Zealand.

Mary E. Power

Department of Integrative Biology, University of California, Berkeley, CA 94720, USA.