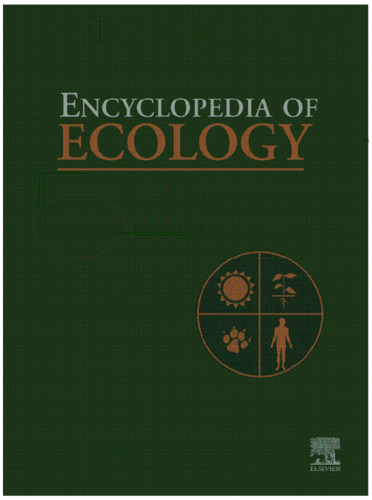

A Georges, L J Hone, and R H Norris. Applied Ecology. In Sven Erik Jørgensen and Brian D. Fath (Editor-in-Chief), General Ecology. Vol. [1] of Encyclopedia of Ecology, 5 vols. pp. [227-232] Oxford: Elsevier.

another point of view in getting insight into future ecological systems.

In this scenario, 'ecological informatics' has a potential for growing as fast in ecological applications as bioinformatics grew in studies at cell or individual scale. It is not predictable, however, to what an extent and how 'ecological informatics' will evolve during the next decades. It will be certainly influenced by advances in computer science, but only our ability to deal with increasingly complex ecological problems will foster 'ecological informatics' as an independent discipline.

In fact, when new technologies or new methods are developed, their application to existing disciplines is usually regarded as a spinoff that may define a subdiscipline, and this is the present state of 'ecological informatics'. However, when a subdiscipline gains enough momentum as to become widely accepted by nonspecialists, it eventually flows back into the mainstream discipline, thus broadening its scope. We hope this will be the destiny of 'ecological informatics'.

See also: Abundance Biomass Comparison Method; Adaptive Agents; Animal Defense Strategies; Artificial Neural Networks; Cellular Automata; Ecological Complexity; Ecological Informatics: Overview; Ecosystem Health Indicators; Empirical Models; Evolutionary Algorithms; Individual-Based Models; Learning; Multilayer Perceptron; Orientation, Navigation, and Searching; River Models.

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Applied Ecology

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Applied Ecology

The science of ecology involves the study of interactions between organisms and their environment, both biotic and abiotic, with particular focus on those interactions that determine their distribution and abundance. Applied ecology is the science of the application of ecology to contemporary problems in managing our biological resources. It includes scientific study of the effects of humans on the interactions between organisms and their environment, but excludes human ecology.

Applied ecology has two broad themes. The utilitarian theme concerns the interests of humans in their food, shelter, welfare, and health, that is, the material services the natural environment provides. Such ecosystem services, once compromised, can be very expensive to replace despite our technological advances. How do we bring ecology to bear in maintaining and improving these ecosystem services where they currently exist, in restoring or replacing them if they have been lost, or in mitigating the impact if those services are under threat? A second theme concerns nonconsumptive values of the biota, for recreation, tourism, psychological well-being, or simply because humans have an ethical responsibility as custodians of the natural environment and the species it contains. How do we bring ecology to bear in conserving these important nonconsumptive values?

These two broad themes overlap, since the nonconsumptive values of the environment are connected through biodiversity to the services healthy environments deliver. Naturally biodiverse systems are typically more resilient to human-induced perturbation than are systems that are highly modified, structurally simplified or degraded, and so are better able to sustainably provide the ecosystem services we expect.

Topics included under the broad discipline area of 'applied ecology' are those where ecological knowledge and understanding are brought to bear on policy setting, decision making, and practice. The directions of the discipline are very much driven by the problems given priority by contemporary society, its governments and industry.

Some Iconic Examples

The scope of 'applied ecology' is very broad indeed, possibly best illustrated by way of example. It is now widely accepted that the global climate is changing, that part of the cause is associated with industrial development, and that the impacts on human communities and the biota are potentially profound. Can we predict how natural ecosystems and the species they contain will respond, what have we done to constrain those responses (e.g., widespread fragmentation of habitat restricts range shifts), and what can we do to ameliorate the impacts of global climate change on the biota? It is in answering these questions that 'applied ecology' complements climate change studies by meteorologists, geographers, and geologists in other disciplines more focused on studying the direct impacts of climate change on human society.

Land clearing for forestry, pastoralism, and agriculture and aquatic habitat destruction through land reclamation and water resource development are arguably the most serious threats to biodiversity today. The long-term consequences of such activity is often not realized at the time it is undertaken, and there is no good appreciation of how far the system can be pushed in meeting production goals before both ecological and economic sustainability are compromised. When land use and water resource development have overshot sustainable levels for production and for other land-use values such as biodiversity, what can be done to restore those values (restoration) or bring about change leading to an acceptable and sustainable condition (rehabilitation)? Both restoration and rehabilitation are important components of 'applied ecology'.

Protected areas such as reserves and national parks make an important contribution to biodiversity conservation (**Figure 1**), but are they adequate to sustain biodiversity in the long term? The overall goals are to conserve species, their genetic variability and potential to respond to environmental change, and the natural ecosystem processes that provide the ecological context in which they have evolved and continue to evolve. Protected area management, the inventory of values and selection of reserves, their design, and the management of threats to their values such as feral animals and weeds, fire management, impacts of human visitation are all topics addressed in part by 'applied ecology'.

Figure 1 Less than 1% of native temperate lowland grasslands of Australia remain intact, and that which remains is fragmented and under continual threat from agriculture, pastoralism and, in the Australian Capital Territory, urban expansion. Inset: The striped legless lizard (*Delma impas*), one of the many endangered species that rely on native grasslands. Photos: Sarah Sharp and Will Osborne.

Globalized trade and associated movement of people and products leads inevitably to unwanted introduction of exotic species, some of which become established in the wild well outside their natural range. This is of major concern because feral populations can be reservoirs for disease that impacts on agricultural production. They can wreak havoc on native species through predation (stoats in New Zealand and foxes in Australia), competition (rabbits in Australia), or interference (zebra mussels in North America). Can we predict which species are most likely to establish, which are likely to cause the greatest impact, model the spread of exotic species when they arrive, and control their spread, distribution, and abundance in order to manage their impacts once they are established?

These are examples of the broader societal context in which 'applied ecology' does its work. The discipline is generally seen to add value to restoration ecology, habitat management and rehabilitation, management of invasive species (both native and exotic), conservation biology, wildlife utilization, protected area management, and agroecosystem management. The discipline also makes important contributions to environmental forensics, landscape architecture, ecotourism, and fisheries.

Foundation in the Fundamentals

The diversity of concepts drawn from ecology and applied in management of our natural resources is vast and stems from the multidisciplinary nature of natural

Table 1 Topics in 'applied ecology' and concepts, ideas, and topics in ecology that are used in applied ecology

Topics in applied ecology	*Relavant ecological concepts, ideas, and topics*
Restoration ecology	Niche, succession, community dynamics, resilience
Habitat management and rehabilitation	Habitat selection, niche, community dynamics
Management of invasive species	Population dynamics, predator–prey relationships, competition, disease–host interactions, natural selection.
Conservation biology	Population dynamics, population genetics, population viability, biodiversity
Wildlife utilization	Population dynamics, sustained yield
Protected area management	Island biogeography, population viability, biodiversity, ecotones
Agroecosystem management	Competition, biodiversity, natural selection
Forensic sciences	Genetics, taxonomy
Landscape architecture	Connectivity, fragmentation, movements, metapopulations
Ecotourism	Population dynamics, thresholds, resilience
Fisheries	Population dynamics, sustained yield, food webs
Forestry	Population dynamics, sustained yield, demography
Urban development	Habitat, corridors
Ecosystem services	Nutrient cycling, biodiversity
Climate change	Niche, population dynamics
Pollution	Niche, assimilation, bioaccumulation, ecotoxicology
Energy generation and carbon management	Nutrient cycling, bioaccumulation
Water management	Niche, biodiversity assessment

resource management generally. In dealing with the impacts of climate change on the biota, for example, we need to know of the habitat requirements of species or 'niche breadth', the extent of suitable habitat and connectivity that provides scope for 'invasion' of new areas as the climate shifts. Coupled with this is the need to know of the limitations to their 'physiological tolerances', their 'dispersal capabilities' and the 'demographic attributes' that will govern the speed of their response through range shifts. Many reptiles have temperature-dependent sex determination, and would appear appallingly vulnerable to climate change. What scope do they have to respond to climatic change, through 'natural selection', which in part will depend on 'genetic diversity' in the traits determining their 'evolutionary responses' to changing climate. Will an evolutionary response be rapid enough? What scope do species have to respond through 'phenotypic plasticity' rather than a direct evolutionary response. Table 1 provides a link between fundamental ecological concepts, principles, and ideas, and the broad areas of application in 'applied ecology'.

What Do Applied Ecologists Do?

Applied ecologists engage in their profession at a broader level than commonly recognized. On the spectrum of esoteric research (of no identifiable immediate relevance), through strategic research (of broad relevance) to tactical research (of immediate relevance), applied ecologists vary in their level of engagement. Some are practitioners at the coalface of application undertaking research in the immediate context of management problems, and addressing the immediate concerns of management. Their work is typically funded directly by resource management agencies or industry.

Others address research questions of more fundamental strategic value, in areas where improved knowledge, understanding, and techniques are likely to be of service in addressing contemporary problems as well as problems of the future, many of which are currently unforeseen. Their work is typically funded by research and development (R&D) organizations or by government agencies such as the US National Science Foundation, the Australian Research Council, the UK Natural Environment Research Council, or the NZ Marsden Scheme.

Application often draws support from unexpected quarters, and an important element of the development of the discipline of 'applied ecology' is the need to provide tertiary education and research funding in a broad strategic context. There must not be too great a focus on immediate needs in funding applied ecological research, lest we risk passing by many opportunities to build the knowledge base from which solutions for the future can be drawn. At an individual level, it can be argued that to be a good applied ecologist, one must be a good ecologist with a broad research agenda, but also with a keen eye out for application and a willingness to engage in those applications when opportunities arise.

Applied ecologists use one or more of the following approaches in conducting their science – observation, experimentation, and modeling. Any one study or topic may be studied and resolved using combinations of the approaches. For example, conservation of large kangaroos in Australia involves observational studies of kangaroo ecology – knowledge of reproductive cycles, diet, and behavior are all important to managing kangaroo populations. Experiments may be undertaken to explore causal relationships, perhaps involving exclosures and population manipulation to determine responses of vegetation, or to fine-tune survey and monitoring approaches. Modeling may be applied outside the scope of feasible experimentation to investigate the combined effects of environmental changes and human intervention on kangaroo populations as a tool to guide decision making. Some topics, such as large-scale climate change, can initially be studied by observation to quantify the changes that are or not occurring. Field experiments may be impossible, especially at large spatial scales, but small plot or laboratory experiments can provide useful information. Modeling provides a framework for integrating these observations and results of the limited experimentation that is possible to estimate likely changes in environmental conditions and responses by organisms to such changes. Future observations can be used to evaluate the accuracy of predictions of the modeling.

The mix of approaches that are used by applied ecologists is determined by their experience with each, the advantages and disadvantages of each including the costs, practicality, and the quality of data and hence the strength of conclusions obtained by each approach. For example, on the latter point, observations allow clear conclusions to be made about patterns in ecology. However experiments allow clearer conclusions about cause and effect in ecology; that is, about what causes changes in distribution and abundance of organisms compared with what changes have occurred. Modeling allows a great range of possible management actions or scenarios to be examined and a greater range than that can be examined by experiments. However the modeling results are hypothetical and require evaluation of their practical relevance.

Success through Communication and Engagement

Applied ecology measures its success in part by adoption of what it has to offer management. Successful adoption demands communication of results in a form that can be readily comprehended by resource managers and effectively brought to the table in policy setting and decision making (**Box 1**). There are a number of challenges to bring about effective communication.

The first challenge arises from the different cultural perspectives of scientist and manager. The core objective of a natural resource manager is to bring all available knowledge and understanding, scientific and otherwise, to bear on setting policy and making and implementing a decision. At the end of the process, the outcome is evaluated, and the decision confirmed as appropriate or not. For an ecologist, as a scientist, learning that the knowledge and understanding brought to the decision-making process was confirmed as appropriate is satisfying, but from the perspective of his/her discipline, it is potentially pedestrian. Science advances through failure, focuses on the causes of that failure, reevaluation of concepts and principles, collection of new data, and re-application. Managers want the problem solved – they get excited when it all goes well; scientists want to learn something new – they get excited when something unexpected happens. Lack of appreciation, and lack of reciprocal respect, for these differing perspectives can lead to breakdown in trust and with it, loss of communication.

Adaptive management, that is, adopting an experimental approach to management intervention, provides a good framework in which scientists and natural managers can work together to achieve solutions to both management problems and advances in knowledge. Under this framework, management intervention is conducted in a rigorous experimental framework where the intervention is implemented as a scientific experiment. Due attention is paid to the fundamental tenets of experimental design and sampling – the use of temporal and spatial controls against which the effects of interventions can be measured, proper replication of experimental treatments, proper attention to sample unit selection and sample sizes. The management intervention occurs in the context of a solid scientific foundation for the monitoring and evaluation that follows. The benefits of an experimental approach to management intervention are that the ecologists and natural resource managers are working together at all stages of the design and implementation of the intervention, the evaluation of the efficacy of the intervention is on a solid scientific footing and so the intervention can be recast in the light of the outcomes with confidence and, perhaps most importantly, knowledge is advanced both when the intervention is successful and when it is a failure. Adaptive management of natural resources is 'applied ecology' at its best.

A second challenge faced in applying ecological knowledge to natural resource management is ensuring that all important information is available to management at the time of setting policy, making decisions, and putting policy into practice. Traditionally, communication of the results of ecological studies occurs in the presentation at learned conferences and by publication as scientific papers in leading journals such as the *Journal of Applied Ecology*, *Ecological Applications*, or *Biological Conservation*. While there have been efforts to better integrate scientists and natural resource managers into professional societies, the primary audience for these channels of communication remain ecologists and other scientists. The audience for refereed publications in journals is primarily comprised of applied ecologists and other scientists.

Many organizations responsible for natural resource management have limited in-house ecological capacity

Box 1 Melding ecological principles with urban planning

At the time of the first European settlement in Australia, lowland areas of southeastern Australia had one of the largest areas of native temperate grassland in the world. These grasslands are now among the most endangered natural communities in Australia (Figure 1). The Australian Capital Territory (ACT) contains about 5% of the high-quality primary native grassland that occurred in the ACT prior to European settlement, home to a number of threatened animal species, including the legless lizard *Delma impar*, the mouthless moth *Synemon plana*, and the matchstick grasshopper *Keyacris scurra*. The expanding Australian capital city, Canberra, is placing continual and increasing pressure on these grasslands and presents city planners with the very great challenge of melding grassland conservation with the relentless expansion of suburban and rural urban development.

Planning for suburban development is a complex process, and planning decisions are made throughout the construction phase. Ecological theory is not in a form that can be used by urban planners, who continually need to assess the costs versus the benefits of planning decisions. Too often the cost–benefit analysis is driven entirely by financial considerations.

Applied ecologists were given the challenge of devising a set of principles that would govern the type and quality of ecological information brought to the planning process and that would enable planners to assess alternatives in the context of both financial and ecological considerations. The principles they devised are as follows.

1. Both regional and local objectives are required for conservation planning on the local scale.
2. Both species and functional communities need to be considered.
3. Knowledge of key life-history properties of species and dynamic processes within the ecological communities is essential for sound conservation planning.
4. Spatial scale is important when assessing the value of published knowledge of species and communities.
5. Common as well as rare species have a bearing on conservation planning.
6. The quality of available data and therefore its value to conservation planning, varies depending on its taxonomic and spatial resolution, seasonal biases, and temporal representation.
7. Areas considered for conservation should be those of the highest value for meeting local, regional, and national objectives.
8. Conservation value includes concepts of size (viability), diversity, representativeness, distinctiveness (rarity), and naturalness.
9. *Diversity*. Conservation areas that possess greater heterogeneity of environmental attributes (floristics, vegetation structure, abiotic components), within the bounds of those conditions known to support lowland grassland communities, are better than those that are largely homogeneous.
10. *Size*. Larger contiguous conservation zones are superior to smaller zones, or zones of equivalent size that are fragmented, all other considerations being equal.
11. *Shape*. Conservation zones that have a large area to perimeter ratio are better than those that are irregular in shape, elongated, or whose boundaries project into suboptimal habitat.
12. Replication of conservation areas in fragmented habitats is necessary as a hedge against catastrophic or stochastic local extinction.
13. Regional conservation planning based on remnants must consider the constraints and opportunities provided by the present and future land-use patterns.
14. Rehabilitation of fragmented habitats should be considered as a means of increasing overall size, buffering, and interconnection.
15. Integration of smaller systems within broader conservation systems increases their conservation value.
16. Consider alternative reserve structures in the light of constraints and opportunities provided by planned development.
17. Conservation zones are not isolated from external influences and careful consideration needs to be given to compatible adjacent land uses, and moderation of their impacts.
18. Include research-based management, monitoring and community participation.

Application of these principles led to the establishment of a series of outstanding urban native grassland reserves in the ACT, reserves that were established as an integral part of the planning and development of the new Gungahlin suburbs. For the applied ecologist, the exercise was communication of ecological principles in a form that could be readily adopted in the planning process, and engagement with planners in bringing about solutions to the challenges of conservation in an urban setting.

for accessing, evaluating, and adopting the results of research presented through formal scientific channels. This in turn can limit the information available to them at the time of making important decisions. Often, decisions are made on a very small base of available information and a limited network of trusted advisers. Many of the larger research organizations address the issue of broadening the base of information available to managers through the appointment of knowledge brokers – individuals employed and often placed within the natural resource agency whose sole responsibility is to broker exchange of management needs in one direction and ecological information in the other direction between managers and scientists, and to assist in providing that information in a useful form. Knowledge brokers and professional science communicators are also engaged to communicate the outcomes of science to the broader public through the media (television, radio, newspapers), community meetings, and websites of ecological associations. Knowledge brokers must have both scientific understanding and communication skills.

A third challenge is to bring ecologists, industry, and management together to build relationships, identify synergies, and achieve broad and lasting ownership over solutions to environmental problems. This is being addressed by governments in many developed countries by providing monetary incentives for science and industry to work together, placing conditions on industry and community participation in government-funded research, and establishing substantial cooperative research entities that bring industry, community groups, and researchers together in well-funded joint ventures. This has changed the face of 'applied ecology', providing many more opportunities for ecologists to engage in research and application of immediate relevance to the economy and society.

Summary

In summary, 'applied ecology' draws its strength from the commitment of ecologists to engage in the application of their science to natural resource management. The discipline relies upon a balance that maintains a strong commitment to broad enquiry going beyond the need for solutions to immediate problems at hand. Information important for solving the environmental challenges of the future will emerge from a broad base of fundamental ecological knowledge and understanding. The discipline also relies on effective communication between the diverse sectors responsible for bringing about effective action on the environment. Applied ecologists do not make policy or make decisions about how to manage the environment. Industry, government, and resource managers do that, and it is up to them to take or reject advice. Ecological knowledge and understanding must be brought to the table in a form that can be readily understood and adopted by industry, government, and management. The major challenge is for ecologists to recognize the contribution they can make to the triple bottom line of industry, and to decision making in government and nongovernment resource management agencies. Ecologists need to become and remain engaged in informing the process of policy formulation, decision making, and implementation by bringing the best-available science to the table. In a world where environmental challenges are increasing dramatically, responsible ecologists need to have a keen eye out for applications of their work and a commitment to engage with natural resource managers when opportunities to add value arise. This is applied ecology's *raison d'etre*.

See also: Adaptive Management and Integrative assessments; Biodiversity; Climate Change Models; Invasive Species; Lake Restoration Methods; Landscape Planning; Mine Area Remediation; Weed Control Models.

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Aquatic Organisms

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Introduction

The length of food chains and complexity of food webs in aquatic systems – which includes fresh, marine, and brackish waters – are set by the productivity of the autotrophs (i.e., photosynthesizing organisms like phytoplankton, epiphytes, macroalgae, and water plants) and by the number of species and niches within the ecosystem. Analyses of ecosystem structure and behavior have traditionally included essential components of the planktonic community such as bacteria, phytoplankton, zooplankton, and fish populations.