APPLIED ECOLOGY

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Contents

Summary

Applied ecology has many facets but the foundation is the use of ecological processes and structures in human efforts related to conservation of nature through to remediation of pollution. Ecosystem Management and Conservation is emphasized here, with focus on the theory of Island Biogeography as the main behind the practice of management and conservation. Local and larger scale issues are examining, with particular care to spatial features like metapopulations. The use of breeding, genetic engineering, and cloning in applied ecology is a relatively recent topic – and one of some controversy – hence there is some emphasis in this contribution. The complexity of reassembling nature is addressed as it pertains to restoration ecology, ecotoxicology and remediation as related to pollution management, and pest management. The main conclusion is that

1. General Introduction: What is applied ecology?

In many parts of society - at least in North America and in academia - there is a disturbing tendency to dichotomize knowledge into "theoretical" and "applied". This is disturbing for two reasons. One is that "theoretical" has almost become a pejorative that indicate ideas of no consequence and that "applied" information is the only aspect worth pursuing. Two, this dichotomy belies the reality of all knowledge: that theory and application are inextricably linked. In fact, no knowledge is purely theoretical or applied. Theory leads to tests and applications that, in turn, refine the theory. In science, this is a fair description of the hypothetico-deductive method that allows testing of hypotheses under replicable conditions. Fundamentally, however, science is about application of a theoretical framework of naturalistic explanations and not all science is amenable to fully replicable experiments in the strictest sense. This is because outside of a laboratory, it's difficult or even impossible to find true replicates. Hence, much of science that addresses large scale and complex questions involves mensurative studies that do not manipulate but use statistical analyses to compare variables observed over multiple locations of (hypothesized) different conditions and over time.

Ecology has been caught in the maelstrom of debate about theoretical and applied science, and the utility of laws ecology. In part this is because ecology has the near-unique problem of encompassing phenomena and forming hypotheses about processes that are hard to test in any replicable fashion, as scientific method demands. To some, this means that ecology is mostly theory.

Additionally, ecology is rather new as a discipline and, in fact, really demands knowledge of many disciplines that focus on diverse spatial and temporal scales. An ecologist must be comfortable with mathematics, chemistry, physics, geology, genetics, taxonomy, biochemistry, physiology. Once, these areas of study (within ecology) were mostly confined to smaller spatial and temporal scales, e.g. an ecologist might study how a population consisting of several hundred individuals might survive for two or three years. Over the years, ecologists were limited by technology - especially computing power, statistical tools, funding, and, sometimes, philosophical expectations that a good ecologist would be a reductionist. However, it is now apparent that an ecologist can study localized individuals and phenomena or he/she can study long-term changes in ecological processes at much larger scales, e.g. watershed, landscape, biome.

Whatever the scale of interest, an ecologist needs to appreciate that they only may be grasping part of the overall picture. Someone studying populations of one species probably misses how community, ecosystem, and landscape processes affect the populations. Those studying longer-term trends in population changes over time using paleoecological methods or climate forecasting models or larger-scale landscape changes will miss most of the subtle changes in individuals. There is nothing inherently wrong with focusing on one scale or another – it depends on the type of question being asked.

The phrase "type of question being asked" is relevant to discussions of what makes ecology "applied". The short answer is that there is not a great conceptual leap from "theory" to "application" in ecology. Application simply means that ecological knowledge is used to solve specific problems that are of concern to humans. Such knowledge has been used for millennia, albeit not with the appellation "applied ecology", since humans started recognizing how to raise crops and domesticate livestock. Over time, humans have sometimes forgotten the value of what we now call applied ecology but continued to use it, however unintentionally, in agriculture, horticulture, and hunting.

We eventually began to recognize the need to use our knowledge to reduce the impacts we have on the planet's ecology and to repair some of the damage. This has been motivated by altruism and ethics but also by self-interest as we recognize how humans rely on much of the ecological processes we have blithely taken for granted for so long. And so, at the beginning of the 21st century, applied ecology has become more formalized. For the purposes of this volume, applied ecology will emphasize ecosystem management, ecotoxicology, restoration ecology, conservation, and biological control but it could easily be extended into other fields, e.g. agroecology and urban ecology. This section will examine the latest advances in various "topic" areas of applied ecology and also examine how different approaches are used in these different topic areas.

2. Ecosystem management and conservation

2.1. Introduction

An ecosystem describes processes like the movement of nutrients through soil, water, and air as they are used and transformed by various individuals ("nutrient cycling") and how these are influenced by - and also influence - the physical processes (e.g. erosion of soil, weathering of rocks, precipitation, drought, fire) and biological processes between and within individuals of various species (e.g. parasitism, herbivory, predation, reproduction, birth, growth, death, decomposition, emigration).

Humans usually define an ecosystem by the general structure that allows us to conjure up a mental picture of what that means and what kinds of processes we expect even though ecosystems don't really have just one boundary – there are too many physical, chemical, and biological interactions to count and few of these overlap nicely enough to define a tightly bounded ecosystem. Most of Earth is more like a complexity of ecological gradients; there may be enough similarities that we can loosely define an ecosystem or at least a recognizable change between locations as an "ecotone".

Nonetheless, humans need an easy vernacular to communication and so we speak of ecosystems that are associated with deserts, wetlands, tundra, forests, or prairies. We tend to mix scales in our description of ecosystems; for example, a wetland is usually something you could walk around in an hour but "tundra" describes a much larger area. Even though the scales are mixed, both "tundra" and "wetland" descriptions are too broad. Wetlands exist in relatively small, localized areas all over the Earth; about the only common feature of a "wetland ecosystem" is that there is standing water visible above the soil for some period of the year. While "tundra" covers large contiguous areas across the Northern Hemisphere, localized variation means that the "tundra ecosystem" is a really a broad categorization that ignores local features.

Similarly, we may speak of a type of ecosystem to help define a place that people can understand but it is inaccurate because it implies that the ecosystem is self-contained and isolated. For example, a small grove of trees (say 1 ha) might be called a forest but it really does not have a separate ecosystem. It is true that there may be certain expectations for how an ecosystem functions in this forest but this function depends on hat is outside and what interactions exist. A forest is in the middle of a city will function differently than one in the middle of farmland or one surrounded by open unmanaged grasslands. It may be true that there is a sudden and dramatic different in how an ecosystem functions between a forest and a grassland so that the two are nearly separate systems but there will be some interaction between them, even if it is restricted to transfer of water and nutrients, that prevents their complete isolation.

Increasingly, there have been questions about the proper scale of focus, prioritizing for conservation and the issue of decision making under uncertainty, how to put conservation into practice, and reviews of ecosystem management. Nonetheless, species still tend to be the focus.

There are many reasons species have been the scale of interest. Humans have psychological reasons for conserving certain "attractive species" that are usually symbols of hope for conserving nature in the broad sense. Other species are of economic interest and thus "worth" the economic and scientific effort to conserve. Still other species, ecological functions, or physical structures may be viewed as "keystones" for continued functioning of the larger, more complex communities and ecosystem in which they dwell, hence conserving keystone species could mean that the seemingly intractable ecosystem can be conserved with relative ease. Conveniently, many "attractive" species are the focus of many scientific studies, thereby compiling information that makes it easier to do further research in the species' conservation. Similarly, it is easier to capture the imagination of the public and funding agencies by focusing on "attractive species" that have a long-established iconic status, thereby ensuring continued research funding, support, and, pragmatically, a continued prosperity in a scientist's career. Thus, if you read the literature on conservation, you will find many studies on seals, whales, pandas, the California condor, the bald eagles, lions, tigers, and elephants. Most of these qualify as "megafauna" (large animals) and are familiar to many as symbols of attempts to conserve at least parts of nature.

While there is value is studying species, especially those that do act as keystones, it has been recognized that conservation will not succeed without conserving the habitat or, more specifically, the ecosystems in which species exist. To minimize this dichotomy of scales, many studies have tried to examine the relationship between the different kinds of species found (biological diversity at the species scale) and the sustained function of ecosystems as a whole.

The basic threads of the argument are whether species diversity is a cause or a consequence of ecosystem sustainability, and whether many species could be eliminated without harming the ecosystem (species redundancy). These ideas all may apply to different ecosystems at different time periods and it is hard to predict which will apply. It is this lack of certainty that makes the rivet popper hypothesis attractive as a basis for environmental management in general though even here the hypothesis may not be applicable to every situation. Put simply, there may indeed be a lot of redundancy of species in their contribution to ecosystem function just like humans place more rivets than absolutely essential to keeping an airplane wing intact. Species - or rivets – can be removed before a catastrophic change happens (the ecosystem changes, wing falls off and the plane crashes). The problem is that we never know beforehand how many species – or how many rivets – can be removed safely; we figure this out after it is too late. This effectively is a restatement of what is now called the precautionary principle: don't act unless you have enough information about the consequences and, if you do take a risk, do not be surprised if the consequences are unexpectedly problematic.

2.2. Island Biogeography

Like other conservation efforts, studies involving large scales like ecosystems sometimes are promoted for their symbolic value, e.g. the tropical rainforest is arguably the most potent symbol. However, serious conservation efforts require that we understand the community and ecosystem dynamics that support and interact with individuals of species of interest. This is the challenge for applied ecologists. How do you try and study something as complex as an ecosystem? The answer is that you do so with humility, knowing that a complete understanding is not possible and, more practically, you do so using mensurative studies that rely on advanced statistical models and knowledge. For some scientists, this might be too daunting an answer. If there is no hope of a controlled experiment or a complete understanding, then some believe it is better to avoid the question and study nothing beyond the scale of a species. Again, studying species is a worthy pursuit and the approaches used are still important to conservation. Nonetheless, science cannot abandon the task of ecosystem research. As complex as an ecosystem may be, there are theories that lead into methods and tools that can be used at a larger scale. It is at this scale, the discussion can begin.

A key concept in modern conservation is "island biogeography" as it is the theoretical basis for much of the last 50 years of research – though I caution this does not mean the theory has not changes nor does it mean the theory applies rigidly in every case. This concept was one of the first to examine conservation at larger, or "landscape" scales. Island biogeography can be conceived of in a literal sense – how do species colonize islands in oceans and what determines their survival? Island biogeography turned out to be a relatively powerful concept because it also applies to conservation on continents, especially when applied ecologists developed ideas of how populations survive in a fragmented landscape, i.e. a series of "islands" suitable for survival of many species that are surrounded by "oceans" of disturbed lands that cannot support most species for long. This is exactly what much of the Earth looks like now since humans have exploited land for our own purposes (industries, residences, farming, transportation). Hence, island biogeography offers insight into how individuals react to living on the islands humans have left them.

When applied to continents, an "island" means a relatively isolated type of ecosystem surrounded by dissimilar types of ecosystems. An individual that attempts to leave its original "island" that contains a suitable ecosystem must find another suitable "island". It must navigate and survive any inhospitable areas between the islands to successfully emigrate. Why must it emigrate? Because an island has limited resources and can only support a limited number of individuals of various species. An individual may find itself without suitable mates, insufficient food, or lack of residential space. A smaller island likely will run out of resources before a larger island will.

If an individual must leave to survive and it does so, then it must find a new suitable island. If there are other suitable islands that are nearby and/or these islands are large in area, then these likely will be colonized by sufficient numbers of individuals of emigrating species to establish new populations on the islands. This is because there is a higher probability of colonists finding these islands at random or at least a higher probability of colonists able to use whatever phenotypic advantages they have to successfully emigrate.

To some extent, whether an individual emigrates at all will be affected by deterministic and stochastic factors of environment and demography. Broadly translated, this means that each potential emigrant will be will be influenced by it’s the deliberate and random events involving the environment, relationships to conspecific and heterospecific individuals, and its own genotype and the phenotypes that result. This may result in a greater propensity to emigrate deliberately (e.g. an animal might be able to comprehend the cues that indicate a need to escape to a new island to survive).

An individual also may be prompted to emigrate because of a fire or a housing project. Other individuals may not emigrate because they are good competitors and have sufficient resources or they may not be able to do so. For some species, stochastic factors may have greater influence, e.g. a seed that must be dispersed by a specific animal can have all the right adaptations and still not emigrate because the animal never finds it or simply carries it to a location only a short distance away in the same island.

If conservation were simple, we would recommend that humans create a whole series of large, closely spaced reserves. However, aside from being politically unlikely, there are ecological reasons not to do this. It turns out that while island biogeography helps us understand how colonization occurs, it is important to consider how individuals, populations, and ecosystems change over time, i.e. their dynamics. This means that the size or proximity of islands alone will not be the only factors affecting survival. Cumulatively, the decision in conservation has been termed as a question of “SLOSS” – design Single Large Or Several Small conservation reserves.

2.3 Connectivity and Structure

One of the problems conservationists face is that an ecosystem that is fragmented into small, isolate islands may not function properly. In many situations, ecosystems slowly change over space. For example, the northern “tree line” is not really a line but a gradual change from forest to open tundra over several hundred kilometers. This area of change is an example of an ecotone alluded to earlier in discussing ecological boundaries. It represents a change in the dominant processes or climates that influence ecosystem structure and function. On a smaller scale, this transition may be more abrupt (e.g. from forest to wetland) but even here it usually changes over tens of meters. However, in ecosystems drastically disturbed by humans, the structure is often altered so the transition is abrupt and spans a few meters.

For example, humans will cut forests so they suddenly end in a line of trees next to a farm field or housing development. This means that there is a definite “edge” to the structure and often exposes formerly-sheltered parts of an ecosystem to new environmental conditions. The species that reside in what used to be an interior forest that is now exposed to wind and light from the farm next to it probably will not survive long. They will either perish from environmental change or from competition by new colonists that exploit the edge environment. This "edge effect" is self-sustaining because the new colonists outcompete the interior species and thus gradually eliminate structures like large trees that provided an interior forest condition. Eventually, the remnants of the interior forest are eliminated even though no further human activities may occur. The islands get smaller and become inhospitable to would-be colonists from other interior forest habitats. This edge effect may diminish the ability of ecosystems to support desired species but some native species do prefer edges and defining when an edge effect has or will occur can be difficult.

From the perspective of migratory individuals, isolated small islands may be more than just inhospitable. They also may be hard to find, hard to reach because of inhospitable lands around it and already over-exploited because the islands are too few in number. One proposed solution to all this, especially in terms of moving between islands, is to connect the islands with a safe corridor. Many species cannot or will not traverse areas between islands because the perceived risk is too risk. This is understandable if you think of simple examples like animals trying to migrate between oases in the desert, attempting to cross open farmland without being detected by predators or trying to cross a busy highway. While some species do not require safe corridors, many large animals will not survive without them.

Thus, conservation scientists may attempt to connect two smaller islands by purchasing or restoring a corridor of similar structure between them. This creates a larger island that may support migration within or reduce the edge effects described above. Corridors, in one sense, could be unwanted in general if they are simply transportation lines like roads. More commonly (in the use of the term corridor as a deliberate habitat connection), corridors also can facilitate migration of unwanted organisms, especially diseases. Corridors also may be too narrow to allow migration or are so narrow that they are vulnerable to edge effects. For this reason, corridors must be designed to be large enough to withstand or minimize these problems; this is not always feasible if land is too expensive or not available. Ultimately, the debate over the benefits and perils of corridors continues and decisions weigh each case's unique set of issues rather than follow a standard recipe of when to implement a corridor or not.

2.4. Metapopulations

If there are no other suitable islands, the individual and, ultimately the entire population or perhaps species to which it belongs may be doomed. Extinction of an entire species that is restricted to one "island" is more likely because it takes only random event of harsh weather or one deterministic event like road building. Even on a large island, individuals may not encounter enough environmental variation to select for different genotypes or phenotypes and a large enough event (like global climate change) might eliminate the species because not individuals will be able to adapt to change.

In most cases, however, there are many suitable islands for different individual of various species to colonize. The islands are not exactly alike in terms of size, shape, ecosystem function, or species composition and usually are at different stages of ecosystem development (unless some mass disturbance like a volcanic eruption created new islands at roughly the same time).

Having different islands means that individuals of different species are constantly migrating and attempting to colonize islands. As long as the islands are close enough, and connected enough, to allow migration and different enough so that no one genotype or species dominates, then there will be a complex mosaic of many genotypes of many species. Constant disturbances may create new islands while periods of no disturbance may allow some islands to literally grow together to create a larger island.

The different periods, types, and intensities of disturbance (or lack thereof) means that individuals are subjected to ever changing selection pressures. If the disturbances are relatively local and do not occur swiftly, then it can be described as “intermediate”. Though this is not true in all situations, some studies have shown that intermediate disturbances create sufficient selection pressures so that no one genotype or species dominates, i.e. there will sufficient genetic and species diversity to cope with most any scale of environmental change (or disturbance) and most ecosystem functions will be filled (or potentially filled) by different species.

At a population scale, this mosaic of constantly emigrating individuals is called a “metapopulation”. While most of the interactions take place within one island, there will be interaction via migration between islands. If one local population on one island goes extinct for any reason, then there will be other populations with enough genetic diversity to ensure the species survives and perhaps migrants can re-colonize islands. Genetic diversity is a metapopulation’s strength and arises because the different local islands create local selection pressures.

More genetic diversity means more than just an ability to withstand changing environments; it means there is more potential for colonizing new islands with different local environments. The key controversy is whether populations necessarily behave as metapopulations and, like most other ecological issues, the answer seems to be case-specific.

Theoretically, the implications of metapopulations are little different than general evolutionary ecology save for the idea that there is some spatial influence on gene flow. Organisms and their habitats survive as long as there is sufficient genetic diversity within to adapt to changing environments. Thus, intermediate disturbances that create or operate within smaller islands create the conditions needed for conservation. If the genetic diversity is lost because of gradual elimination of too many ecosystems that contained local populations, then a species may be doomed to a slow extinction under conditions of “inbreeding depression” – the loss of genetic diversity and increased accumulation of alleles detrimental to survival - and changing environments.

For example, this is exactly what is happening with many of the great cats, like panthers, pumas, lions and tigers, across the Earth. In many species of great cats, the remnants of a once abundant species are restricted to a few islands. The islands may be large in area but if these are dominated by a few genotypes, there will be insufficient genetic variation to adapt to environmental changes both local, like human encroachment, and large, e.g. climate change. Even if no environmental changes occur in the short term, the low genetic diversity often creates the problem of inbreeding depression. This means that the remaining individuals are so closely related that any offspring they produce suffer higher than expected disabilities. At the genetic level, this occurs because there is a higher probability of offspring produced by relatives having multiple copies of alleles that cause genetically based conditions. In some cases, the offspring produced may not be viable so no live offspring are produced or they die before reproducing themselves.

2.5. Selective Breeding and Hybridization

Historically, the response to inbreeding or generally insufficient amounts of genetic variation to allow species to survive has been to rescue species by selectively breeding between two disjunct populations. This has produced many of the agricultural, forestry, and horticultural species used. Humans must intervene to transport either the individuals or their gametes (in cases of artificial insemination or similar processes) to introduce new genetic material. While it may work in some disciplines, the relevance for conservation is less clear. Deliberate hybridization of species, as is common in agriculture and related disciplines, has some ethical, legal and ecological consequences for conservation. A major one is whether the species is conserved at all because it is, in fact, a new species (a hybrid).

Even if hybridization is to occur between spatially isolated populations but still within one species, it is possible that there are no longer disjunct populations and/or not enough new genetic material anywhere. A specific problem is that disjunct populations may be too dissimilar in their genotypes to allow successful reproduction or survival and may depress fitness. This genetic dissimilarity within species is caused by local adaptations and isolation from other populations (usually found great distances away) and the problems created are referred to as “outbreeding depression”.

2.6 Genetic Engineering

There probably will be increasing interest in genetic engineering as one solution. At present, insertion of new genetic material is mostly limited to single genes or complexes that produce specific products. Currently, some species at risk could have new genes inserted that help them survive in the wild, though legislation does not permit it because of real ethical concerns and fears that inserted genes could create unexpected problems, e.g. the species could become a pest, the inserted genes may be copied by a virus, unexpected gene products may harm the species we mean to save.

It soon might be possible to repair malfunction genes or alter genes that cause genetically based disabilities but this will carry similar risks and be very expensive. Generally, there are – and will be – concerns that genetically modified organisms (GMOs) will outcompete or hybridize with species at risk or that the use of GMOs will encourage overuse of fertilizers and pesticides and farming of marginal land that otherwise would have been used for conservation.

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Biographical Sketch

Stephen D. Murphy is an Associate Professor in Environment and Resource Studies at the University of Waterloo and Cross-Appointed to the Department of Geography and the School of Planning. His B.Sc. (Honours) in Biology was received in 1988 and his Ph.D. in Biology was conferred in 1993; both degrees are from Queen's University at Kingston Canada. He completed a post-doctoral fellowship/research associate position in the Department of Crop Science, University of Guelph, 1993-1996. Dr. Murphy's research began with studies in physiological ecology as applied to populations and successional communities of exotic and native species in abandoned (ex-arable) lands. His specialization was in biochemical interference as part of interspecific competition, a phenomenon called "pollen allelopathy". Research at Guelph focused on extending all of this more explicitly to weed management and agroecosystem analysis. Since joining Waterloo in 1996, Dr. Murphy has expanded the application of cross-scalar ecological work (physiological to watersheds; agricultural to urban to protected areas) within the context of invasive species management, ecological restoration, ecological monitoring, and most aspects of environmental management. He is currently Chair of the Society for Ecological Restoration Ontario, Co-Chair of the Parks Research Forum of Ontario, and Co-Director of Research for Canada's newest urban charitable ecological research trust, an organization and a site known by the one-word name of "rare".