Conservation Biology and Wildlife Genetics

Kathmandu University
Dhulikhel, Nepal

Organised and sponsored by

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The problem

Professor Jacques van Alphen

Human population growth and consumption of resources are important drivers of global environmental change, resulting in environmental degradation, and loss of biodiversity.

The tragedy of the commons.

An important reason, why maintaining biodiversity is so difficult, has been described by Garrett Hardin in 1968. He reasoned that common grazing land would be overexploited, because all the benefits to let an extra animal graze on the commons would fall to the owner of that animal, while the costs would be shared by all the users of the commons. This would result in overgrazing of the commons because everyone would put in extra animals to get the short-term benefit. This is what happens to open access resources like the oceans, or the atmosphere. Treaties are the only way to resolve the tragedy of the commons.

Hardin’s model suggests that natural resources are inherently prone to over-exploitation.

The major environmental problems are:

- Habitat conversion and modification,
  - deforestation
  - habitat fragmentation
  - desertification
  - intensification of agriculture (pesticides, salinization and erosion of soils etc.)
  - urbanisation

- Climate change
  - range dislocation
  - loss of adaptation
Example: A loss of Fynbos biome area of between 51% and 65% is projected by 2050 (depending on the climate scenario used), and roughly 10% of the endemic Proteaceae have ranges restricted to the area lost. Species range projections suggest that a third could suffer complete range dislocation by 2050, and only 5% could retain more than two thirds of their range.

Eutrophication and acid rain

(illegal) trade in threatened species
- (Tiger, Rhinoceros)

Biological invasions
- Invasion of pest species in agriculture
- Invasion of pathogens (Dengue fever)
- Competitive displacement or extinction by predation
Intrinsic value
Of course, biodiversity has an intrinsic and an aesthetic value. For that reason we should make that our children and grandchildren and the generations coming after them can still enjoy the diversity of life that we experience. However, some people see the world in a more mechanistic way, and ask if the world would function less well if a species would go extinct.

Ecosystem functions: productivity & stability
They argue, that ecosystems contain redundant species, and will continue to function if those species would disappear. They accept that some species might be important for the functioning of an ecosystem, and that such “Key Stone Species” should be preserved, because their disappearance would precipitate the disappearance of other species and result in collapse of the ecosystem.

However, even if some species are key-stone species, do other species have no effect on ecosystem functioning? We will show in this lecture that biodiversity as such is important in ecosystem functioning, and hence that its preservation has more than an aesthetic value.

The following ecosystem functions of biodiversity have been demonstrated:
- Biodiversity stabilizes community and ecosystem processes.
- When climatic variations harm some species, unharmed competitors increase. Such compensatory increases stabilize total community biomass, but cause species abundances to be more variable. These results support both the predictions of Robert May concerning the effects of diversity on population stability and the diversity—stability hypothesis as applied to community and ecosystem processes (e.g. productivity), thus helping to reconcile a long—standing dispute.
High biodiversity as a controller of ecosystem function and insurance against ecological collapse

Larger numbers of species are probably needed to reduce temporal variability in ecosystem processes in changing environments.

Reductions in species richness increase ecosystem vulnerability to invasions, enhance the spread of fungal diseases, and alter the richness and structure of insect communities.

The loss of basal species may have profound effects on the integrity and functioning of ecosystems.

Lord Robert May with the extinct Tasmanian wolf
What do we need to know about Ecology to manage biodiversity?

Community ecology.

Professor Jacques van Alphen

**Community Ecology; Multitrophic interactions**

Community ecology is the science of interactions between organisms forming a (local) community. Such a community consists of organisms in different trophic levels: plants that compete for light and soil, herbivores that eat plants, and so modify competition between plants and succession in vegetation. Some herbivores eat the fruits of plants and help them to distribute their seeds. Predators, parasites and pathogens cause mortality among herbivores and affect the spatial distribution of herbivores. They may cause variation in time in population numbers of herbivores. Finally there are detrivores that break down dead organic material and so close the cycle of nutrients.

**Community Ecology; Top-down and bottom-up effects**

When predators regulate the numbers of herbivores, this is called top-down regulation. When the amount of available food regulates the numbers of herbivores, this is called bottom-up regulation. The classical populations cycles of snow-shoe hares and Lynxes in Canada where long time considered as evidence for top-down regulation of the hares by the lynxes. More careful analysis of the data later showed that snowshoe hares are regulated by both their food, and their predators, hence that the cycles are not only caused top down, but also bottom up!

Lynx, not a top down regulator of snowshoe hares, but numbers oscilate in response to hare numbers!
Community Ecology; Keystone species

A top predator that regulates the numbers of herbivores is often a keystone species. Likewise, an herbivore that determines the composition of the vegetation is also a keystone species. Removal or addition of a keystone species will have effects that cascade through all trophic levels and through the whole food web. An example is the release of a large predatory fish, the Nile Perch, in Lake Victoria in Africa, which resulted in the extinction of hundreds of endemic cichlid fish species, and in changing the food web and the productivity of the lake.

Community Ecology; The ecology of fear

A top predator that does not regulate the numbers of herbivores can still be a keystone species. The presence of the predator can influence the foraging behaviour of herbivores, and thereby have important effects on the vegetation. Herbivores may avoid areas associated with a high risk of predation. Even if they do visit such areas, they may spend an important part of the time in scanning for predators, and less time on browsing and grazing. Also, the mere presence of a predator may induce herbivores to live in larger groups, and to be less selective in food choice. Such changes have impact on the heterogeneity of the vegetation and on the species composition of the vegetation.

Community Ecology; Density-dependent regulation

In the early days of theoretical ecology, ecologists were aware that the species around them had persisted on earth for millions of years, and that population numbers of most species did not fluctuate dramatically. They reasoned that some form of feedback had to exist in nature that stabilizes the numbers in natural populations. Such feedback can result from density dependence: At higher density, competition for food increases, and reproductive success decreases. At higher densities, predators may kill an increasing percentage of the population and pathogens and parasites may spread more easily, resulting in increased mortality.
There is ample evidence for density dependence in nature. More difficult is to show in specific situations that density dependent processes stabilize a population. Much of the mortality in a population is density independent. Most environments fluctuate in a stochastic way, and unpredictable bouts of adverse weather (droughts, flooding, spells of very cold weather) may cause important mortality. So, even with density dependent processes buffering populations, stochastic processes may cause large variation in numbers over time. Large populations, spread out over a large area can hedge their bets against adverse periods and persist, in particular in heterogeneous environments, where part of the landscape can be used as a refuge against the adverse weather.

**Small populations**

When populations are small, as is the case for rare species, they are no longer buffered against stochastic fluctuations in the environment and, therefore, the probability of extinction is high. If habitats become fragmented and populations subdivided into small subpopulations, local extinctions of subpopulations can result in the demise of the whole population. Small populations are vulnerable for more reasons: at low density, the individuals may experience difficulties they do not encounter in larger populations and therefore have lower fitness.

Warder C. Allee brought attention to the possibility of a positive relationship between aspects of fitness and population size 50 years ago. The Allee effect can be regarded not only as a suite of problems associated with rarity, but also as the basis of animal sociality. The Allee-effect describes a scenario in which populations at low numbers are affected by a positive relationship between population growth rate and density, which increases their likelihood of extinction. Such a positive relation may come about because in small populations individuals have problems in finding partners for reproduction, or in defending themselves against competitors or predators, or in exploiting food-items that require attack by a group. Recent evidence now suggests that the Allee effect might have an impact on the population dynamics of many plant and animal species.
What do we need to know about Ecology to manage biodiversity?
Spatial ecology.

Professor Jacques van Alphen

Island Biogeography

The observation that the species diversity of oceanic islands increased with the size of the island and decreased with the distance of the island to the continent inspired Robert H. MacArthur and Edward O. Wilson to develop the theory of Island Biogeography. They reasoned that the number of species on an island was an equilibrium between the number of immigrant species arriving on the island and the number of species going extinct. Smaller islands have higher extinction rates, and therefore fewer species, while islands further removed from the continent receive fewer immigrants and therefore have also fewer species.

This simple conceptual theory has become important in conservation biology, when biologists became aware that fragments of habitat on land could also be considered as islands, although not surrounded by water, but by unsuitable habitat.
**Fragmented landscapes**

Research on fragmented ecosystems has focused on the biogeographic consequences of the creation of habitat “islands” of different sizes. Like real islands, these habitat fragments harbour often small populations subject to random extinction over time. Like real islands, the larger the fragment, the lower the probability of extinction and again like real islands, the number of species in a fragment depends on the probability of colonization by species from elsewhere. This probability depends on the distance of a fragment to undisturbed habitat, but also on the distance between fragments. Management of fragmented habitats, by increasing the connectivity between fragments (e.g. by corridors) could help to maximize the probability of recolonisation after local extinction of a species.

However, ecosystem fragmentation, apart from biogeographic changes, causes also large changes in the physical environment. Fragmentation generally results in a landscape that consists of remnant areas of native vegetation surrounded by a matrix of agricultural or other developed land. As a result exposure to radiation, wind, evaporation, and availability of nutrients are altered significantly. These in turn can have important influences on biota within remnant areas, especially at or near the edge. These consequences vary with the time since isolation and distance from other remnants, and degree of connectivity with other remnants. The adverse effects of the fragmentation process are smaller in larger remnants.

Management of, and research on, fragmented ecosystems should be directed at understanding and controlling these external influences as much as at the biota of the remnants themselves. There is a strong need to develop an integrated approach to landscape management that places conservation reserves in the context of the overall landscape.

**Meta-population dynamics**

The metapopulation concept provides a very powerful tool for analysing the persistence of spatially subdivided populations, in terms of a balance between local extinction and colonization. It was first formalized by Richard Levins in 1970 and further developed by Ilkka Hanski and coworkers.
It is based on the idea that small populations cannot persist and will go extinct with time, but that a network of local populations can persist, because empty habitat patches can be recolonized, counteracting the effect of local extinctions.

**Source and sink dynamics**

For the conservation biologist it is important to be aware that some habitat patches cannot sustain a viable population of a species. The fact that the species may present in such patches, is a consequence of metapopulation dynamics: after extinction the patch becomes recolonized by individuals from a source population, but the new population is again not viable and goes extinct and so on. The patch that cannot sustain a population does not contribute to the metapopulation: it is a sink!

There is ample evidence that local extinctions of fragmented populations are common. From this it follows that recolonization after local extinctions is critical for regional survival of fragmented populations. The probability of recolonization depends on (1) spatial relationships among landscape elements used by the population, including habitat patches for breeding and elements of the inter-patch matrix through which dispersers move, (2) dispersal characteristics of the organism of interest, and (3) temporal changes in the landscape structure. For endangered species, which are typically restricted in their dispersal range and in the kinds of habitat through which they can disperse, these factors are of primary importance and must be explicitly considered in management decisions.

Corridors: Corridors can be used to connect fragments of wildlife habitat, yet the identification of conservation corridors typically neglects processes of habitat selection and movement for target organisms.

There are few controlled data with which to assess the conservation role of corridors connecting refuges. If corridors were used sufficiently, they could alleviate threats from inbreeding depression and demographic stochasticity. For species that require more resources than are available in single refuges, a network of refuges connected by corridors may allow persistence.
Conservation Genetics to manage biodiversity

Professor Jacques van Alphen

Small populations: Inbreeding
The costs of inbreeding in natural populations of mammals are unknown despite their theoretical importance in genetic and sociobiological models and practical applications in conservation biology. A major cost of inbreeding is the reduced survival of inbred young. Experimental estimates of this cost from the regression of juvenile survival on the inbreeding coefficient using pedigrees of 40 captive mammalian populations belonging to 38 species gives the following. The average cost of a parent-offspring or full sibling mating was 0.33, that is, mortality was 33% higher in offspring of such matings than in offspring of unrelated parents. This is likely to be an underestimate for natural populations.

Small populations: Genetic Drift
Genetic drift is the overriding factor controlling the loss of genetic variation. Mutation has no noticeable effect on populations of the size typically managed in zoos and nature preserves. Immigration from a large source population can strikingly slow, halt, or even reverse the loss of genetic variation, even with only one or a few migrants per generation. Unless selection is stronger than commonly observed in natural populations, it is inefficient in countering drift when population sizes are on the order of 100 or fewer. Subdivided populations rapidly lose variability from within each sub-population but retain variation across the subpopulations better than does a panmictic population. These results suggest that population managers should be concerned with the variation-depleting effects of genetic drift, perhaps almost to the exclusion of consideration of selection and mutation. Drift can be countered by the introduction of very occasional immigrants or, less effectively, by division of the managed population into smaller breeding groups that interchange enough migrants to prevent unacceptably deleterious inbreeding within each subpopulation.
Measuring fitness and stress in natural populations

One of the most difficult tasks in conservation biology is identifying populations subject to stress before such stress has a detrimental impact on the population, thus allowing conservation and remedial action to be undertaken. Measuring fitness (fecundity, survival, etc.) changes directly is often difficult, expensive, or impractical. The ability of an organism to buffer its development against disturbances (developmental stability) is often considered an integral component of an individual’s fitness. However, a number of studies have established a clear relationship between developmental stability and fitness in response to both genetic and environmental stress. Consequently, developmental stability may be used as a surrogate for more direct fitness estimation for use in conservation biology and biomonitoring programs. Potentially it could have a widespread application as an early warning system for monitoring the effect of genetic and environmental stresses on natural populations.
Measuring genetic diversity

Dr. Laura Bertola

In general, biodiversity can be divided into three levels: ecosystem diversity, species diversity and genetic diversity within species. A variety of genetic techniques can give us insight into these levels of biological variation. Crucial for this is the source of the DNA. Typically, the highest quantity and the highest quality of DNA is extracted from blood or tissue samples. However, when these are not available, it is also possible to extract DNA from faecal samples, bones (e.g. from museum collections) or even directly from the environment (e.g. soil or water samples).

Diversity at the ecosystem level can be studied by screening an environmental sample for DNA traces to illustrate the presence of a particular species. Another approach could be to opportunistically collect faecal samples to get insight into the distribution of elusive species. At a species level, one can think of barcoding projects, for confirmation (or rejection) of existing taxonomy. It can contribute to understanding the genetic relationship within a genus or family, but it can also lead to the detection of cryptic species. If we look into more detail into the genetic diversity within a species, we have reached the lowest level of biological variation. This information can give you insight into the evolutionary history of a species, biogeographic patterns and even into the genetic structure of a particular population.
There are a number of genetic markers, which all have a specific set of characteristics. Which marker is most suitable depends on the research question and, to a lesser extent, the quality of the sample. We will briefly discuss the source of genetic diversity and how to study this for a variety of genetic markers. Technological advances have led to the development of new techniques of DNA sequencing, collectively called Next Generation Sequencing. These techniques open up new possibilities, for example by making a new magnitude of unlinked genetic markers available. A few examples will show how genetic data can be processed to answer possible research questions.
How genetics contribute to conservation

Dr. Laura Bertola

Small and isolated populations quickly lose genetic diversity, often referred to as genetic erosion. The resulting problem is twofold: 1) it leads to the loss of evolutionary potential, 2) it can directly affect populations by decreasing fitness. Several scientists have claimed that stochastic factors are much more important and will drive a population to extinction before genetic factors can play a role in this. However, analysis of populations with known levels of inbreeding, as well as comparative analyses of species (endangered versus least concern status) show that inbreeding in natural populations does matter.

Following the island biogeography model, we define three major drivers of genetic erosion in small and isolated populations:

- Inbreeding (island model: area effect)
- Genetic drift (island model: area effect)
- Impaired gene flow (island model: distance effect, to lesser extend: area effect)

These factors play a major role in the extinction vortex, by also affecting demographic factors.
We have gained more insight into the development of inbreeding by following captive populations, or small, restocked parks where pedigree information is readily available. Luckily, inbreeding can be reversed relatively easily by introducing individuals from other populations. There are several examples of species in which immigrants are favoured, even in unmanaged, natural populations. However, management decisions like translocations and, in extreme cases, even hybridization with another subspecies, also have an ethical aspect.

A focus on a higher geographic level, looking at phylogenetic data, can also contribute to conservation by defining Evolutionarily Significant Units or Management Units. This is relevant if the goal is to conserve the complete diversity, including diversity within a single species.

Wildlife DNA forensics is a field in which genetic techniques are used to detect illegal specimen. Barcoding can be used to detect illegally harvested or even dangerous (poisonous) species in commercial products (e.g. endangered orchids in traditional medicine). When biogeographic data of the species of interest are available, these can even be used to track the source population of the illegal material.
Genetic studies can be a valuable addition to current means of studying endangered populations. Further ignorance of the role of genetic factors in a threatened population is likely to result in inappropriate management decisions. Insight in the genetic make-up of species we consider to conserve is a prerequisite for the establishment of effective conservation practices.
Large Carnivores: Are they Key-stone species? Are they Umbrella species?

Professor Jacques van Alphen

To prevent the further loss of species from landscapes used for productive enterprises such as agriculture, forestry, and grazing, it is necessary to determine the composition, quantity, and configuration of landscape elements required to meet the needs of the species present. I will discuss a multi-species approach for defining the attributes required to meet the needs of the biota in a landscape and the management regimes that should be applied.

Umbrella Species

The approach builds on the concept of umbrella species, whose requirements are believed to encapsulate the needs of other species. It identifies a suite of “focal species,” each of which is used to define different spatial and compositional attributes that must be present in a landscape and their appropriate management regimes. All species considered at risk are grouped according to the processes that threaten their persistence. These threats may include habitat loss, habitat fragmentation, weed invasion, and fire. Within each group, the species most sensitive to the threat is used to define the minimum acceptable level at which that threat can occur. For example, the area requirements of the species most limited by the availability of particular habitats will define the minimum suitable area of those habitat types; the requirements of the most dispersal-limited species will define the attributes of connecting vegetation; species reliant on critical resources will define essential compositional attributes; and species whose populations are limited by processes such as fire, predation, or weed invasion will define the levels at which these processes must be managed. For each relevant landscape parameter, the species with the most demanding requirements for that parameter is used to define its minimum acceptable value. Because the most demanding species are selected, a landscape designed and managed to meet their needs will encompass the requirements of all other species.
Large carnivores need large areas of relatively wild habitat, which makes their conservation challenging. These species play important ecological roles and in some cases may qualify as keystone species. Although the ability of carnivores to control prey numbers varies according to many factors and often is effective only in the short term, the indirect effects of carnivores on community structure and diversity can be great (“the ecology of fear”). Perhaps just as important is the role of carnivores as umbrella species (i.e., species whose habitat area requirements encompass the habitats of many other species). The application of meta-population concepts to large carnivore conservation has led to proposals for regional reserve networks composed of wilderness core areas, multiple-use buffer zones, and some form of connectivity (i.e. corridors). The exceptional vagility and the large home ranges of most large carnivores make such networks feasible.
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Himalayan Tiger Foundation

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