Islands and Archipelagos:
European biodiversity issues seen from the Atlantic

Hotel Açores Atlântico, Ponta Delgada, Açores, Portugal

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Background

Islands, and the archipelagos that they sometimes form, possess some of the most unusual and fascinating ecosystems and habitats in the world. They had been famous for their biological riches long before Darwin stepped ashore on the Galapagos to discover delight upon marvel.

These riches had been there not only before Darwin, before Magellan, but before *Homo habilis* chipped her first flint. With the escape of our ancestors from Africa and the subsequent expansion of our own species, hitherto pristine ecosystems throughout the planet were abruptly obliged to cope – or fail to cope – with an animal like none there had ever been. From one moment to the next, in evolutionary terms, they faced an intensity and kind of competition, predation, invasion, disease and outright assault for which they were, and still are, signally unprepared. For various reasons, many of which are discussed in this workshop, the ecosystems on islands and archipelagos were especially vulnerable to this new threat.

Today human communities living on islands face complex challenges, involving both anthropogenic and climatic pressures, as they struggle to protect their natural resources. While many of the difficulties faced by islands and archipelagos are also felt on continents, the problems are thrown into sharp relief by the fragile island setting, the high levels of endemism, and the acute risk of extinction.

On some islands mineral deposits are exploited in a way that adds to the pressures on local biodiversity, but more frequently the local populations of humans on islands have three main sources of income: agriculture, fisheries and tourism. These livelihoods depend in the long term on a healthy environment and on sustainable resource use. Unfortunately, agriculture is often aggressive to native species; fishery is notorious for its lack of husbandry, and island communities frequently lack the resources to manage tourism, and the infrastructure that develops with it, in a way that keeps biodiversity intact. The (often mainland) organisations that promote these economic activities are not necessarily interested in conserving the biological environment.

Commerce is not the only anthropogenic pressure on island biodiversity. People living on islands may have no realistic economic alternative but to overexploit native components of biodiversity, or push native species aside to make room for imported species. Many islands suffer the threat of overexploited off-shore resources, degradation of the marine environment, and pollution from the land. Some struggle to manage oil pollution and solid waste from ships.

There are many consequences of the loss of biodiversity. Economic costs include reduced water quality and supply, reduced harvests and fisheries, and the obstruction or loss of water systems and hydroelectric power through silt. Social consequences include the displacement of rural and indigenous populations, the disruption and possible loss of traditional cultural practices, and a reduction in quality of life.

Island communities have an obvious interest to protect their terrestrial and marine biodiversity, and to encourage sustainable use of the resources that coastal and marine habitats provide. Unfortunately some island communities see conservation and development as mutually exclusive, and there may occasionally be other cultural barriers to conservation.

Rapporteur's summaries of keynote presentations

Keynote speakers at the workshop used the theme of "islands and archipelagos" to draw out and illustrate biodiversity issues of general European importance, for which significant scientific research effort is needed. What follows is are summaries worked up from notes taken during the presentations, but they are not a verbatim report. The speakers have checked these summaries, which should reflect the spirit, if not the detail, of what was said. Any errors are the fault of the rapporteur, your servant,

Martin Sharman

Islands as natural laboratories: endemism, colonisation and extinction

Robert Whittaker - University of Oxford, United Kingdom

Laboratories

Islands have historically been of great importance in biodiversity research for three main reasons. First, each island is unique, and harbours a unique variety of species. In this sense, they provide a huge range of experimental scenarios to the ecologist. Second, they come in all sizes, lie at varying distances from each other and the nearest mainland, and because they have a variety of origins, their geology and soils vary. All these parameters strongly influence the biological history, and hence the past and present ecology of islands. By judicious selection of islands, the scientist can study the effect of each of these parameters in isolation or combination. Third, the dominant biological process driving the changes on the island depends on the size and age of the island: adaptive radiation can be studied in large, remote islands; taxon cycling in large but less remote islands; ecological assembly rules in medium sized islands at moderate distances from the mainland; equilibrium theory of island biogeography in small islands not far from the mainland; and metapopulations in small, inshore islands.

Scientists working on the ecology of islands have proposed many interesting theories, some of which have proved to have predictive power not only on true islands, but also on “habitat islands”, or habitat patches isolated from other similar habitats by an environmental matrix of a different nature. Thus ecological lessons from islands can frequently be generalised to fragmented habitats on the continent.

Endemism

Although the number of species on any given island may be small, it is likely that a rather high proportion of that number will be endemic to the island or archipelago. Island endemics constitute a disproportionate percentage of the world's species, the most startling example being New Guinea, with 15-20,000 plant species, of which 10.5-16,000 are endemic. The Azores have some 300 plant species of which 81 (27%) are endemic.

Various mechanisms on both islands and continental landmasses may tend to isolate species. An example is given by mountain valleys, each isolated from the next by high ridges. Another is the refugia formed in isolated places during successive periods of glaciation. Such isolated environments also give rise to high species and sub-species endemicity.

Species that are endemic to islands are particularly vulnerable to extinction; if that single population is exterminated, the species is then extinct. For this reason islands harbour a disproportionately high proportion of the world’s endangered species, and at the same time a high proportion of island endemics are threatened with extinction.

Extinctions happen naturally, but humans have generated waves of extinctions across the world's islands, including those in the Mediterranean, at rates that are several orders of magnitude greater than natural rates. Of the birds whose extinction has been recorded, 80% concern island species. Most species loss since the 1600s has occurred not in continental forests, but on islands.

Colonisation

Islands are not only places where species meet their ends. Islands are also colonised by species from elsewhere. Scientists can use them to understand how ecosystems are built or re-built. The early and highly influential equilibrium theory of island biogeography modeled colonisation as a simple, stochastic processes. More recent work on ecological traits of island assemblages discloses that colonisation is not random at all, but highly structured. The Krakatau islands provide a good case study that illustrates these structural features, and shows that they vary with isolation, area and complexity of island habitats. Furthermore, colonisers are not independent of species that have already established themselves. A plant that depends on a particular animal for pollination or dispersal is an obvious example, and the interdependence is increased if that animal can only live on the plant concerned. Ecosystems depend on certain species, and the ecosystem that finally develops on an island may be strongly influenced by the identity of early colonisers.

Extinction

The main causes of biodiversity loss, in order, are: (1) habitat degradation, fragmentation and destruction; (2) competition from introduced exotic species; (3) gathering, hunting and other predatory activities of humans; (4) disease, often spread by human activities.

Increasingly, humans reduce and fragment large areas of natural ecosystems. As the surviving habitats become smaller and more isolated, the equilibrium theory of island biogeography predicts that species will disappear piecemeal from the remaining fragments. Fragmented habitats break species into increasingly isolated pockets, each of which is then reduced in detail.

The risk of extinction is not randomly distributed across species. Can we predict not only how many, but which species will disappear? In some cases we can – for example top predators will often be unable to cope with hunting grounds that become more and more dispersed and sparse.

The early collapse of a species is driven by deterministic changes, including climate change, but more especially, by human impacts on the environment, such as hunting, increasing pollution, and the introduction of disease and exotic species. Closer to the cliff-edge of extinction, stochastic fluctuations in the remaining population of the species, and the lack of resilience caused by reduced genetic variation, renders the population vulnerable to stochastic changes in the environment, which can be the proximate cause that wipes out the species.

But if we can make local predictions with some degree of certainty, can we really predict regional and global biodiversity losses? The answer is "no". Our present theories are based on equilibrium theory, which is manifestly far from the reality of the situation, and furthermore do not take scale sufficiently into account.

If we can understand extinction risk better, we may be able to reduce the rate of biodiversity loss.

Research priorities

Real islands hold great biodiversity value, and their particular (often acute) problems deserve priority in both conservation actions and in research. For the scientist, islands are invaluable testing grounds for ecological and biogeographical theory, which can later be applied – but with caution – elsewhere. Caution is needed because island theories cannot necessarily be applied unthinkingly to continental habitat islands. Thus an essential area of high strategic importance for biodiversity science is the understanding of ecological processes on islands, and how the lessons learned can be adapted to fragmented habitats elsewhere.

Research aimed at the reduction of habitat loss and at the control of exotic species is of vital importance. Since tourism and economic development are both booming on many islands, scientific work should be carried out to understand how to conserve biodiversity and make economic activities sustainable on islands. Work should also be aimed at methods tending to reduce human predation on endangered species while taking into account the needs of local peoples.

Unfortunately, the various factors forcing the loss of biodiversity do not act independently. For example, climate change can exacerbate habitat loss, and subsequent changes in vegetation cover influence the climate. Research is needed to understand how these forcing factors interact.

In conclusion, we need research to help to maintain the insularity of islands, while reducing the rate at which continental biota are breaking up into islands.

http://www.geog.ox.ac.uk/staff/rwhittak.html

Questions and answers

Your talk addressed biodiversity of islands as an equilibrium between colonisation and extinction. What about creation of new species in islands? Are there any models? Is there a way to predict the creation of new species?	There are no adeqate models that can accurately predict the development of a new species. Furthermore the timescales involved are typically far too great for humans to have much experience with natural speciation.

(Christian Patermann, DG RTD, EC)	Darwin's mechanism of survival of the fittest provides a way to give a *post hoc* explanation of how species have evolved to fit their current niche. In outline, for a new species to arise there must be a relatively unexploited niche and the existing species must have the genetic variability that will occasionally give rise to offspring with a heritable phenotype that can better exploit that niche than any competing species. Presently, the trend of speciation on islands seems to be negative. In the past, the timescales of speciation and extinction were comparable, leading to a slow increase in biodiversity over geological time. Today extinction rates are thousands of times those of the past. The rate of speciation has not increased, and is now three or four orders of magnitude less than the rate of extinction, and so is quite negligible in the balance.
What is your opinion about nestedness – a rather fashionable issue in modern biogeography? Do you think that this theory can provide us with effective tools for the understanding of the processes concerning island biodiversity? (Sinos Giokas, University of Athens, GR)	One species is always more at risk of local extinction than any other. As pressures increase and that species disappears, another species becomes particularly at risk. If we detect the same sequence from one island to another, we can describe the species concerned as a nested set. This is obviously related to the assembly rules that I spoke about: on any group of similar islands we will get a particular combination of species more or less frequently than we expected. Similarly, extinctions may occur in somewhat repetitive patterns. Because of the inter-relatedness of species, we should not look at individual species, but at complexes of species. This makes the hypothesis of nestedness rather knotty and possibly reduces its predictive power.
Noting (a) that in Europe there are higher levels of endemism in freshwater species (especially glacial relict and groundwater species) compared to terrestrial species, and (b) recent discoveries that coral reef fish have mechanisms to restrict the dispersal of larvae, and that marine seabed-living amphipod crustaceans can have as high levels of endemism around islands as the terrestrial fauna, and (c) that marine (especially invertebrate) species can re-invade land and freshwater habitats on oceanic islands, what would your relative priorities be for freshwater, marine and terrestrial invertebrate research? (Mark Costello, ECOSERVE, IR)	It is impossible for me to assess impartially and with any scientific objectivity the relative importance of these groups. This is perhaps an issue that is more properly dealt with later, after we have heard from all of the speakers, incluing Dr. Billett, who will address the topic of marine biodiversity.

You emphasised the need for "non-equilibrium" theories, on the grounds that the MacArthur and Wilson (1967) equations predict the equilibrium proportion of islands colonized by a species. I believe the truly important distinction is between static versus dynamic models. In the case of dynamic models, one may investigate both the equilibrium and the non-equilibrium states. The problem with the latter is that the answers depend on the initial conditions, in other words on the history of the environment, which makes it difficult to arise at very general conclusions. We will probably never have a satisfactory non-equilibrium theory, even though we can develop non-equilibrium models of species turnover. Ilka Hanski (University of Helsinki, FI)	That is true. But the MacArthur and Willson model is the most generalised of all the models that are available. Nevertheless the equilibrium assumption is is not a realistic view of the world, and we must develop a non-equilibrium view.
Do you think that the public and policy makers are sufficiently aware of these problems, and in particular of the urgent need to slow the rate of extinction? Can individuals do anything personally? How can scientists and policy-makers encourage positive behaviour? Martin Sharman (DG RTD, EC)	No, I do not think that the general public or politicians are really conscious of the seriousness of the situation. Scientists do not do enough to communicate their findings to the public.
Surely the major weakness of island biogeography theory is that it concentrates on numbers of species becoming extinct. It is much more important to identify which species are at risk. How much do we know about which taxa and which types of species within these taxa are at risk? And what are the research priorities in this area? (Alan Watt, CEH, UK)	We have some of the tools needed to do this. I am personally keen to promote macro-ecology, which looks at the emergent statistical properties of datasets. This may allow us to get a start on understanding this difficult and important issue.
I have a very continental view, and do not understand islands. What is the significance of the numbers of species? Why are there so many species on large islands? Miklos Bulla (National Council on the Environment, HU)	The short answer is "buy my book"! (see http://www.geog.ox.ac.uk/islandbio/book.html) Large islands have many species partly because they have the geographical potential to develop many different niches. In the case of New Guinea, for example, habitats range from coastal mangroves and rain forests to dry montane forests.

Islands and archipelagos: pointers to biodiversity research priorities for Europe

José María Fernández-Palacios - Universidad de La Laguna, I. Canarias, Spain

The islands of the European Union have three origins:

Continental islands: are emergent fragments of the continental shelf. They are separated from the continents by narrow, shallow waters. This separation is recent and came about as a consequence of the inter-glacial rise in sea level, which has isolated the species that were already there from the rest of the population on the mainland. They will remain islands for about 20-30,000 years. Examples in the EU include: the British Islands, Gotland, Öland, Xland, Seeland, Fyn, Bornholm, Frisian Islands, Aegean Islands, as well as Saaremaa, Hiiumaa and Svalbard.

Continental fragments: were once part of the continent, but millions of years ago tectonic drift started to separate them from the mainland, with the species they carried. Now the waters between them and the continent are wide and deep. Their life span involves several tens of millions of years. EU examples include: the Balearic Islands, Corsica, Sardinia, Sicily, Crete, Cyprus, etc.

Volcanic islands: originate in underwater volcanic activity. Since they were never connected to the continents, they are populated by biota that have come from elsewhere, and subsequently enriched by speciation. The species found on these islands depend on the dispersion of the continental species. These islands exist for 10-20 million years before eroding back into the ocean. EU examples include: the Azores, Madeira, Canaries, Eolie, Reunion, Martinique, Guadeloupe, Faroe, as well as Iceland and Jan Mayen.

Most of the species endemic to the European Union are found on volcanic islands or archipelagos and on continental fragments. The richness of these islands arises from their isolation and their longevity, respectively. These islands are Europe's biodiversity hot spots, but not all islands are equal in this respect. For example, only 1.2% of the 1,400 species of vascular plants in the British Isles are endemic, while 23% of the 300 vascular species of the Azores and 47% of the 1,300 species of vascular planst in the Canaries are endemic. What are the processes that lie behind this variety?

We now recognise several ecological processes that tend to give rise to a particular biodiversity on islands. Isolation from the mainland is a key to these processes, since not all mainland species will find their way across the water to the island. This leads to empoverishment of island biota in that any given area of the island tends to contain fewer species – and endemics – than an equivalent area on the mainland. Furthermore, some niches which are filled on the continent may be left vacant on islands; this is the phenomenon of "disharmony".

Short-term ecological phenomena observed on islands include the so-called "ecological relaxation" which describes the possibilities open to a species when it is no longer subject to the severe predation, disease or competition that is usual on the mainland. Some species exhibit "niche shift" in which they occupy wider niches from that occupied by the same species on the mainland. In some ecosystems we observe "density shift", when the species are present in densities that are higher than on the continent. All of these effects tend to build singular island ecosystems.

Long-term evolutionary phenomena include "relictualism", or the tendency for species extinct elsewhere to survive on islands where competition may not be so severe, and where the ocean-moderated climate, together sometimes with migration to higher or lower altitudes, partially buffers the effects of climate change. An example is given by the laurel forest tree species which were erradicated during glaciations from their former range in the Mediterranean basin, and which survive today only in the Macaronesian region (Azores, Madeira and Canaries).

Phyletic speciation (when species evolve to produce a single new taxon), adaptative radiation (when species develop along several divergent lines to exploit different niches) and geographic or allopatric speciation (when natural selection or genetic drift act differently on isolated populations) lead to an increase in endemic species which counteracts the initial impoverishment of species on islands.

Islands may give species the opportunity to radiate from few or even one founder events. This can lead to spectacular increases of endemic species and genera, as has been the case for some

Macaronesian plants (*Echium, Argyranthemum* or *Aeonium*) or animals (*Laparocerus, Hemicycla*). Scientists are constantly discovering and desribing island species new to science. For example, in the Canaries the last two decades has seen an average of one new description per week (including four vertebrates).

Endemic species on archipelagos are characterised by a spatial distribution that is frequently limited to a single island. The species may have only a few or even a single population, with few individuals in each population. Often there is little genetic variance within or between populations. Plant species on islands sometimes tend towards extremes of size (gigantism or dwarfism) and they may become woody, while losing their ability to disperse. Lack of predation pressure often leads to the loss of defensive adaptions, while the relaxation of ecological pressure may lead to a loss of ability to compete. In undisturbed island ecology, these characteristics are useful, but in a human-dominated world they greatly increase the vulnerability to extinction.

Endemic species on islands are threatened with extinction from various causes. Humans cause habitat change, fragmentation, and destruction. Humans introduce predators, competitors, and diseases. They hunt – sometimes indiscriminately – and collect food, trophies, souveniers, and ornamentals. They can provoke trophic cascades and pollute the land and water with chemicals. Added to these anthropogenic forces are natural hazards such as hurricanes, volcanic eruptions, floods, landslides and fire as well as demographic collapse and inbreeding depression.

Twenty percent of all bird species live only on islands, but these island species account for 85% of the known extinctions of bird species. Thus the probability of an insular species to become extinct is about 40 times higher than for a continental one. Lord Howe island (Australia) covers about 10 km^2. After humans colonised it, it lost more bird species than Europe, Asia and Africa together!

Within this frame, I firmly believe that biodiversity research in the EU is mainly an island task. Biodiversity research should focus on the increase of knowledge and, urgently, work that can help to develop actions against extinction.

The increase of knowledge should concentrate on a full inventory of species, their vulnerability status, the dynamics of surviving populations, the genetic variance within and betwen populations, and the functioning of the ecosystems where they live.

Research to help prevent extinctions should include methods to protect endangered species in their environments, as well as ways to detect, reduce, and where possible eliminate threats. We need to understand how to rescue species and where necessary how to raise them *ex situ*; how to reintroduce and monitor the most threatened species. We should also focus some research effort on environmental education.

http://www.ull.es/publicaciones/ecologia/jose.html

Questions and answers

The causes for extinctions in islands that you highlighted in your talk seem to be the same as the ones that also apply to extinctions in the continents. Why are then islands better laboratories for biodiversity studies? (Giselher Kaule, University of Stuttgart, DE)	Marine islands are delimited by salt water, and the boundary is therefore very distinct and absolute for almost all terrestrial and freshwater organisms. Metaphorical islands in the continents are surrounded by territory that is more or less hostile depending on the organism concerned. The boundary is less distinct, and therefore less easy to work with. Furthermore we should remember that extinctions on metaphorical continental islands may often be only local extinctions, while extinctions on islands may well mean the complete disappearance of the species.
If we can solve the problems of	I agree. The problem on islands is both more acute

biodiversity conservation in islands, these could constitute good examples for solving these problems elsewhere. (Beudels , BE)	and in a way more clearly defined. It should help us and the policy-makers to focus our thinking and give us a sense of urgency that we might lack in the less defined continental cases.
Do research programmes on biodiversity conservation usually include follow-up actions to develop practical conservation plans? (Sharman, DG RTD, EC)	Unfortunately, no. In many cases the money available for the research is very limited, and while it may cover the basic research it does not allow the scientists to develop good conservation programmes. As I pointed out in my talk, there is an urgent need to improve our fundamental knowledge concerning many species, and this also makes it difficult to develop coherent recommendations for conservation programmes.
New scientific descriptions of new taxa may well concern rare species. As such, these species would merit special care. (Paulo Borges, Universidade dos Açores, PT)	I agree. The reason that such a species is new to science is probably because it has a limited distribution and small population. If money is limited, as it often is, then it should be used to conserve very rare new species. This will involve a re-assessment of the earlier conservation strategy. In other words, if in a given area we have not yet assembled a complete list of the existing species (as is the case for the Canaries), all the conservation priorities have to be reconsidered when species are found that are new to science. For this reason I believe that a substantial effort should be made to assemble a full inventory of species, and that the money to do it should be found as a matter of priority and urgency.

Islands and archipelagos: implications for nature reserves and fragmented habitats

Roseline Beudels - Royal Belgian Institute For Natural Sciences, Belgium

Island and archipelagos: implications for nature reserves and fragmented habitats

How do we apply island biogeography theory in the field of nature conservation?

In 1972 Jared Diamond introduced Mac Arthur and Wilson's theory of island biogeography, an ecological landmark of the 1960's, into the realm of nature conservation. It immediately found considerable success by providing a theoretical framework to help to select, design and evaluate nature reserves.

This success has continued, although in the 1990s the theoretical background shifted from island biogeography to meta-population theory. As far as nature conservation is concerned, the hypotheses and results of the underlying theories are similar, though meta-population theory constitutes a more fashionable formulation. Both theories were antedated by Wright's deme approach, widely used by evolutionists in the early 1960s and essentially identical to metapopulation theory.

The main result of these theories is that smaller more remote islands harbour fewer species than larger, less isolated ones. It is this idea that conservationists exploit in the design of parks.

This theoretical focus has led to some somewhat fruitless discussions such as the "single large or several small" (SLOSS) controversy, over which much ink was spilled in the 1980s, or the current craze, fed by geographic information systems (GIS) and computer mapping, for corridors and ecological networks.

Despite these distractions, what is really of importance to conservation biologists are the factors that govern the relationship between area, distance and numbers of species, and it is these factors and their relationship that should be further investigated.

These factors consist of four overlapping sets:

- area

- habitat diversity

- interspecific competition

- small population phenomena

<u>Area</u>

The number of species in a given territory increases with the size of the territory, whether it be a sample of a larger continental mass or an isolated island.

This is a fundamental biogeographical law, formalized as early as 1921 by Arrhenius and mathematically formulated in 1962 by Preston:

$S = cA^z$,

Where S is the species richness

A is the area of the territory

Z is the slope of the regression line

c is a proportionality constant characteristic of the taxonomic group concerned

There are two reasons that the number of species increases with the area sampled. First, larger samples are more likely to include at least one individual of sparsely distributed species or at least one concentration of individuals of patchily distributed species. Second, since larger areas almost always contain more combinations of abiotic factors, they are likely to provide a greater range of distinct habitats.

Of course these effects apply both to continental samples and to islands.

Habitat diversity

Larger islands normally contain more habitats than smaller ones. One reason for this was given in the previous section: the increased diversity of combinations of abiotic factors. A second reason is that the smaller an island is, the fewer species it contains – for all the other reasons mentioned in these paragraphs. Ecosystems are formed by assemblages of species and the prevailing abiotic factors. Fewer species in the area means a reduced potential to build distinct ecosystems, and hence a smaller diversity of habitats.

Interspecific competition

MacArthur and Wilson's original theory assumes that the rate of immigration and extinction of species on an island eventually stabilises. The identity of species on the island may change, but the number remains nearly constant at the equilibrium number of species. No new species can invade the island unless another species becomes extinct. Ancient island communities are essentially closed, consisting of a stable number of species, most of which occupy a larger ecological niche than they would on the mainland.

Even for oceanic islands, this model is difficult to document. It is probably not applicable to nature reserves whose species cortege is the result of a sample recently (extremely recently, in geological and biological terms) enclosed within the reserve boundary. Nature reserves are not characterised by long-distance colonization over a long period as are true islands. In this respect, none of the traits typical of true island assemblages of species are observed or to be expected in nature reserves.

Small populations

Small areas simply cannot contain as many individuals of any given species as a larger area of the same habitat could.

As populations shrink, there comes a point at which random fluctuations in population size are greater than changes caused by environmental drivers: below this small population threshold, population dynamics are dominated by stochastic rather than deterministic factors. A tiny population whose size is determined largely by stochastic events is in great danger of extinction. Furthermore, small populations are often confined to small areas, which a single catatstrophic event might obliterate, or which could suffer fatal environmental deterioration from a single cause.

At this point it is useful to introduce the idea of the minimum viable population of a species. This is the smallest size of population that has a good chance of survival for long periods without friendly intervention.

What guidelines do we derive from this for the design and management of nature reserves?

Firstly, we learn that habitat diversity is the key to preserving biodiversity. Nature reserves will only preserve regional biodiversity if the protected areas in the region include all the habitats caracteristic of the region. This is almost never possible, and to preserve as much biodiversity as possible, reserves should be selected in such as way that the species they contain differ as much as possible. By maximising γ-diversity (the change in species composition among the reserves), they will also maximise β-diversity (the species diversity of the reserves).

The initial selection of the reserves is only part of the story. If they are to keep their full complement of species, the habitats in the reserves must maintain their quality. Not only must conservation biologists monitor the habitats, but they may have to manage them. Many habitat types, left to themselves, progress towards climax communities. This implies that some species are replaced by others – a change in the components of biodiversity in the reserve. If this happens and the original habitat is not renewed elsewhere in the reserve, biodiversity will almost certainly decrease, perhaps severely. In fragmented landscapes, this lack of renewal is unfortunatly the rule rather than the exception.

Secondly, we learn that size matters. If a nature reserve is to contain a given species, then it must also contain more than the minimum area of the habitat that will keep the species above the small population threshold. The reserve should in fact probably contain a much larger area of this suitable habitat than this minimum, because the habitat should be big enough to contain a viable sample of its own constituent species. This is often a demanding requirement, particularly so in rich tropical, subtropical and warm temperate habitats. Larger species of animals are often missing from the species list of smaller areas because their resource requirements exceed the capacity of small reserves. For this reason, large species are the most susceptible to extinction.

Thirdly, we learn that we must devote constant attention to the population size of the most vulnerable species. Island biogeography helps us to predict what the final number of species will be if nature takes its course in an isolated area. It does not tell us which species will go extinct, or what will drive them to extinction. Nor does it say that we can do nothing to prevent extinction.

In many cases, nature reserves, or their constituent habitats, are unfortunately below the size necessary to sustain minimum viable populations of the species they contain. If we suspect that a species is below its minimum viable population, we must be constantly on guard against a slide towards extinction. We should work to understand the factors that drive population down, and try to identify and implement mechanisms to remove or mitigate those factors.

Are corridors important?

Corridors are linear features that do not increase the area or the diversity of habitat in a protected areas. If they did, they would be an extension of the protected areas, and by definition not a corridor. Corridors provide organisms a path to links areas needed in the course of their activities, and they provide populations with a way to connect sub-populations, increasing population size and reducing the impact of stochastic population changes.

Corridors may certainly be useful, but they must be suited to the ecology of the target species. Bears, bugs, baobabs and bats do not travel together along shared highways like tourists flocking along motorways through the countryside to sunny beaches. Dispersal mechanisms vary from species to species, and a corridor that is perfect to disperse one may be useless to disperse another. Similarly each species has its own ecological requirements for a corridor, even though it will only use the corridor in transit. Corridors are not abstract green lines connecting protected areas on a GIS. They are well-designed, protected, biological entities.

What research is urgently needed to help conserve biodiversity?

The following themes are crucial:

To conserve biodiversity we must preserve ecosystem diversity. This requires a thorough typology of ecosystems, their main caracteristics, and their regional distribution. While in some countries we have quite satisfactory inventories and maps of popular species and species groups, we are still lamentably short of reliable inventories and maps of habitat types at a level of detail and precsion that is useful for practical conservation. Their completion is an urgent priority.

We know theoretically that protected areas must include adequate areas of key habitats. We still do not know what constitutes an adequate area. How big must the habitat be to include not only the caracteristic cortege of species, but a large enough area to ensure viable populations of those species – and of the constituent species of the habitat itself? Research is urgently needed on the area requirements of species. At present we have some ideas for the larger species, but even there, huge gaps exist.

We know that we must maintain habitat quality. Research is needed to develop low-cost, reliable, rapid assessement methods to monitor habitat quality, reliable techniques to manage habiats, and cost-efficient ways to monitor the effect of management.

Although the last decade has seen progress in modelling the dynamics of small populations, the models do not always work well in field conditions. Research is needed to improve their power to identify the factors that are most likely to put a population at risk of extinction, and hence to propose suggestions for actions to reduce the risk.

http://www.naturalsciences.net/cb/

Questions and answers

Have any reserves been established along these guidelines? (Mark Costello, ECOSERVE, IR)	These guidelines are an essential base of the Natura 2000 network. Many protected areas included in the network were established on the basis of the CORINE habitat typologies. Habitat typologies have been used for the establishment of Protected Areas in Australia. As indicated in Buenos Aires CBD COP in 1996, the National Park Service in Argentina is using them to test the adequacy of their network of protected areas. The development of habitat typologies have been requested by countries such as Brazil and Equatorial Guinea for the purpose of developing networks of protected areas. Of course, many existing reserves are often a legacy from the past, and it is difficult change their boundaries or to establish new ones on more ecologically sensible grounds. The theory is important to help to make better management decisions, however.
For conservation purposes, is it sufficient to maintain habitat diversity when one considers other causes of biodiversity loss such as the introduction of exotic species? (Christian Pattermann, DG RTD, EC)	No. Habitat diversity conservation requires us not only to protect the whole area of habitats, but also to maintenan or rehabilitate the quality of their components. This includes control of alien species, which can be an important agent in the degradation of habitats and communities.
We heard in the previous presentations that island species are sometimes characterised by the loss of competitive ability. In turn, this exposes the species to extinction when a strong competitior appears on the island. Doesn't our protection of species in nature reserves lead us into the danger of reducing the capacity of those species to react to outside threats? (Christian Pattermann, DG RTD, EC)	No. The objective of establishing protected areas is to maintain as much diversity as we can, which means that competitivity is not decreased. And because areas of protected areas are often too small, we often have to manage them in such a way as to maintain biomasses and diversity higher than those which a natural habitat could support: competition is therefore certainly maintained as well. Changes in the characteristics of most species, including the ability to react to threats, are typically linked to genetic change. In fact it is difficult to change the capacities of species, even when we try. To give an example: there are about 200 000 flowering plants in the world, of which humans have managed to domesticate about 100, and of this only 12 produce 80% of our food. Out of 150 species of large terrestrial herbivores, humans managed to domesticate only 14, of which only 5 (cow, pig, horse, goat, and sheep) are widespread in the world. The concern is not that we will remove the capacity of organisms to protect themselves. The concern is that we are not doing enough to protect them. We must work hard to extend the network of protected areas – we cannot talk about "completing" the network, because it will never be extensive enough to protect all species. Furthermore, protected areas are not the complete answer, and we will need

	special measures to protect and preserve certain species outside networks.
There is much research activity in Europe on refining the existing algorithms that aim to select sites for nature reserves. These models allow the manager and scientist to analyse the benefits and costs associated with the selection of a particular site for protection. The opportunities to apply these modelling results to conservation, e.g. in the context of Natura 2000, have probably not been examined adequately. Ilka Hanski (University of Helsinki)	Several methods are being applied in the development of the Natura 2000 Network, both by the Services of the Commission and by the Member States.
This question is aimed at the three previous speakers. In how far is it possible to assess the impact of climate change on the biodiversity of European islands and archipelagos? Are there any climate models that look at the impact of climate change on biodiversity? Is there any indication from research of such impacts, for example on migratory species of birds? This is the type of cross-cutting inter-disciplinary question that should be addressed by research proposals. How could we accommodate such research under the biodiversity bullet of our key action? (Anver Ghazi, DG RTD, EC)	Individual species react individually to climate change. This means that any such model would have to address each species individually. Furthermore, the climate is constantly changing, and species have coped with climate change ever since life began. Despite this, we do not understand the relevance of climate change in connection with past speciation or extinction processes. (Whittaker)
The previous question and answer deals with the creating of bio-physical models. How do we combine physical scales with biological scales? How can you model population dynamics while taking in to account the physical models of climate and ocean? (Public, PT)	
How do we select the habitats that we want to preserve? As you say, preservation programmes must address the issue of size and scale in defining protected areas, and this has not been done in European programmes such as Natura 2000. Natura 2000 is an artifical and arbitrary selection of sites, that is not based on a rational selection such as their total biological diversity. Sites are proposed without detailed evaluation of biodiversity patterns, sometimes because the data are missing. And yet as you say, the rational selection of sites is absolutely necessary. (Sinos Giokas, University of Athens, GR)	Yes, indeed, the rational selection of sites is absolutly necessary, but I believe the process is closer to that that you give it credit for. Scientific arguments however are not necessarily the only ones that must be taken into account. Political considerations are often more important, and often condition the implementation of networks of protected reserves.

There is general lack of knowledge – let us say ignorance – concerning endemic invertebrate fauna. At the moment the approach is not balanced. As a minor example, only about 2% of Greek endemic terrestrial invertebrates are classified as endangered or vulnerable, which is probably very far from the truth. Consequently, there is an urgent need in Europe to re-evaluate the criteria we use to describe the vulnerability of species or to evaluate biological diversity. (Sinos Giokas, University of Athens, GR)	I entirely agree with this comment on the lack of information coming from invertebrates in the evaluation of biodiversity. This is due to the lack of data on invertebrates that could be used for rapid assessment purposes. It will be the responsibility of invertebrates biologists to fill that gap.

From islands and archipelagoes to metapopulations on the European continent

Ilkka Hanski - University of Helsinki, Finland

For humans and a few other species, the dominant trend over the past few centuries has been globalization. For most other species in Europe, the dominant trend has been just the opposite, insularization.

The theory of island biogeography brought into sharp focus the effects of area and isolation in influencing the processes of extinction and colonization, and suggested a means of predicting the standing crop of island biodiversity. Biodiversity is reduced the more isolated and the smaller is the area of suitable habitat. This theory marked an important conceptual advance, but is too simplistic for today's management problems. Furthermore, it is difficult to test the theory, because it is very difficult to examine colonisation and extinction. The reason for this is that the timespans involved are so long.

For various reasons, then, the theory of island biogeography is not widely used any longer. Its place has been largely taken by the theory of metapopulation dynamics. There are many similarities between the two theories, including their focus on area and isolation effects. The main difference that the metapopulation theory tends to be applied to networks of small habitat fragments without a mainland that would help to supply species and to support a long-lasting population. What was once only an issue of islands is now a problem for species throughout their range.

The spatial distribution of a species is not static at any scale, but fluctuates under the influence of local extinctions and colonisations. Increasingly, as human activities spread and intensify all over the planet, the local extinctions become more and more common, and suitable habitats are broken up into fragments. For example, vast areas of Europe were covered by forests in historical time – the recent past, for biological systems. Now these forests are wiped away, their remnants existing in tiny, widely-scattered fragments. A tree in such a fragment does not in any sense "see" a hospitable continent around it. It sees an environment just as hostile as the ocean is to a terrestrial species on an island. In many ways it is worse: there is no "mainland" forest to act as a reserve for these fragments.

Dr Beudels told us about area-dependent local extinction. We should also remember that the probability of re-colonisation of an island depends on how isolated it is from any other source of that colonising species. The condition for persistence of a species depends on the properties of the network of habitat fragments and on its dispersal capacity. Extinction occurs in a single habitat fragment for many reasons. The species will disappear completely from the archipelago of fragments if the network is too sparse and the average fragment size is so small that the extinction rate of populations inhabiting the fragments in excessively high.

We know that extinction risk increases with decreasing population size. But we should also bear in mind that the smaller the popultations, and the more isolated the fragments, the smaller becomes the probability of re-colonisation. We must therefore conceive of a "metapopulation capacity", or the total amount of suitable habitat in a network and how it is fragmented. How small are the pieces? How widely are they scattered? The concept of metapopulation capacity considers the total area of the habitat and its spatial configuration. It uses these variables to determine the capacity of the landscape to support viable metapopulations.

We can use this approach to generate models with high predictive power. For example, they can predict the consequence of habitat loss at regional scale. Indeed, the metapopulation theory has in many cases been successfully applied to species living in highly fragmented landscapes at the regional scale. Application of the theory to European (continental) scale is less straightforward.

For instance, to what extent can the European-wide Natura 2000 reserve network be analysed in the context of the metapopulation theory? Are the goals for the Natura 2000 network adequately defined? Does the Natura 2000 network work? Does it cover European biodiversity adequately?

Climate change will have major consequences for biodiversity in Europe, not least because it will interact with landscape structure. To what extent will climate change interact with past and ongoing habitat fragmentation? In the past, species have coped with climate change by migrating from a less favourable climate to a more favourable one. Thus forests may migrate up and down mountainsides, or steppe covers and uncovers the desert. But fragmented landscapes and habitat isolation will certainly hinder such movements in the future.

Habitat loss and fragmentation have occurred for a long time in some parts of Europe, but are more recent processes in other parts of Europe. The dynamics of species respond with a time delay to habitat loss and fragmentation. In other words species do not respond instantly to changing landscape structure, especially when we consider the rapid rate of change caused by human activities. To illustrate this point, consider what happens to species when the environment becomes less favourable.

In any given environment, rather a low number of species are very common. Again, not many species are very rare. Most species are not common, but not rare either.

Common species are common partly because they manage to track changes in their environment with relative ease. A few rare species will go rapidly extinct following habitat change, but many species become initially increasingly rare without going extinct. However, it would be wrong to assume that these species would necessarily survive for a long time in the current environment (no further adverse changes). Many such newly-rare species may just be responding slowly to landscape change, being on their way to extinction, but the ultimate extinction may take a relatively long time. In a very real sense, such species can be described as "living dead" - they can only survive if the quality of the environment is improved for them, they will not survive if the environment remains unchanged in its current state or if the quality of the environment further deteriorates.

To what extent is our perception of the state of Europe's biodiversity biased by this kind of delayed response of species to landscape change? We see little change, but the model tells us that many species may already be among the living dead.

Although we have models that can be developed for species in highly fragmented landscapes, research is needed to validate them. Most of all, however, we must understand how time lags work, and how they influence our perception of thresholds for rarity and extinction.

http://www.helsinki.fi/science/metapop/

Questions and answers

There is general belief that the proportion of common species should increase with habitat fragmentation. Your model does not seem to predict this. (Allan Watt, CEH, UK)	That would be the ultimate outcome of habitat fragmentation. But in the transient period, when many currently rare species haven't yet had time to go extinct, we will actually have an overabundance of rare species.
I wonder whether we over-stress the lag effects in response to changing climate. Most species seem to have tracked climate change at the end of the ice age quite rapidly. Does the capacity of a species to track climate change depend on what kind of climate change it is? Perhaps different taxa will respond in different ways, and differently again depending on the kind of change. (Rob Whittaker, University of Oxford, UK)	It is probably easier for a species to track natural climate change than it is for them to cope with anthropogenically-induced habitat fragmentation, because the former process is so much slower. Climate change combined with habitat fragmentation will be disastrous.

Your model looks at the past, present and future distribution of common and rare species. Can it accommodate differences in various biological properties of species, such as intrinsic ability for dispersal? For example, spiders and beetles differ in their dispersal ability and in their spatial distribution in tree canopies. (Paulo Borges, PT)	No, the model is simple and does not include much specific biology. It does include species differences in extinction probability, and other species-specific properties could be included.
Habitat remnants are not normally random samples of habitats. There are often special reasons for their preservation. They may differ considerably in quality from an average sample of the original habitat. Can you accommodate habitat quality in your metapopulation model? (Lennart Hansson, Department of Conservation Biology, SLU, SE)	At the moment the model does not do this, but it would be possible to qualify habitat fragments by a measure of their quality.
You used the chilling phrase "the living dead" to characterise many of the surving species in Europe. Yet underlying this awful vision is the assumption that the landscape is rapidly fragmenting. But judging by landscape paintings and early photographs, the European landscape does not seem to have changed much during the last 100 years. Are the present rates of habitat loss and fragmentation rates really that alarming in Europe? (Martin Sharman, DG RTD, EC)	The perception of an individual is not necessarily reliable when it comes to judging changes in fragmentation in the landscape. Agricultural practices have changed considerably across Europe over the last 50 years, and are still changing today with rapid intensification. We can now expect very abrupt changes in the land use practices in the accession states as they prepare to join the Union. Together with increased urbanisation and a denser system of transport networks, human activities are increasingly threatening habitat integrity throughout Europe.
In a way, networks of reserves such as Natura 2000 can be bad because people will only care about reserved patches and neglect other areas. This will drive towards increased fragmentation. (Jorge Palmeirim, University of Lisbon, PT)	The quality of the matrix, or habitat between the patches, is clearly important. This is an issue of connectivity. The quality of the surrounding habitat influences the ability of individuals to survive. We as a society should therefore invent ways to maintain habitat quality in the areas outside the protected reserves.
There is much talk in US science circles about an integrated natural reshaping to improve habitat and landscape quality. The idea is that anthropogenic influence tends to degrade the habitat. Can we go back and look at what things were like 200 years ago and try to reshape the landscape to what it was like then? Is this a good methodology? Can we measure its success? (Christian Patermann, DG RTD, EC)	For the first part of the question, it seems unlikely that we might in Europe be able to reverse trends and restore things to what they were in 1800. The deterioration of the landscape is an observed fact, and I have only spoken about the way the models can predict the effect of decreasing landscape quality. Nevertheless the models I have described can also be used to examine increased quality of the habitat. In this case they predict increasing trends in biodiversity and so can be used to predict restoration success.
The landscapes of southern Europe and the Mediterranean are unique. In these landscapes it is difficult to decide what is a	Yes, although even in these landscapes spatial population dynamics are likely to be important. The models I have discussed cannot yet be applied to

patch. Organisms often have very large home ranges. In these landscapes we are often still in the process of gap formation rather than in the presence of a highly fragmented landscape. (Francisco Moreira, Centro de Ecologia Aplicada, PT)	such landscapes. In fact it is an important challenge to develop models that could make useful predictions for this kind of environment.

Invasive species on islands: consequences and management options

Thomas Elmqvist - Swedish Biodiversity Centre, Uppsala, Sweden

In 1722 Captain Jacob Roggeveen reached Easter Island. He found an island barren of trees and with a small impoverished population, but with clear evidence of a great, and recent, civilisation. The most startling evidence was the architecture and of course, the giant stone statues, or moai, now toppled, but once facing menacingly out to sea. Ever since that first European brought back the news to Holland, historians have puzzled over the enigma of Easter Island, also known as "Rapa Nui" and "Isla de Pascua".

From about AD 400 to 1550, Rapa Nui's population increased from a small handful of people to about 7-9,000. Much of their culture, industry, building material and food supply depended on the palm forests that covered the island. These *Jubaea* palms, endemic to the island and revered by the Polynesians, are now extinct.

From 1400 to 1600 the inhabitants industriously created the moai. Then abruptly, in the century before first contact with Europeans, Rapa Nui society collapsed as deforestation, soil erosion, and a loss of biodiversity accompanied or even provoked bloody civil war. The islanders toppled all of the Moai. By the time Roggeveen found them, there were only about 200 people left on the island. What triggered this disintegration?

Some scholars say it was a textbook example of population expanding until it overwhelms resources. Easter Island is now used as a metaphor for human-enduced ecological disaster: "the island is so small that the person who felled the last tree could see that it was the last tree" – and hence the human species is doomed, because economic imperatives drive us to insane ecological destruction.

Archaeologists have now started to question the "over-exploitation" interpretation and point out that the civilization lasted for hundreds of years in reasonable ecological equilibrium with the resources of the island. This equilibrium was maintained with the resource management techniques known elsewhere in Polynesia. If over-exploitation was not responsible, what was?

The Polynesians who colonized Rapa Nui accidentally brought with them *Rattus exulans* (Peale, 1848). The Polynesian rat is a co-voyager, a vagrant, now found throughout the Pacific islands. Diamond (1995) suggested that the rat was largely responsible for the extinction of a parrot endemic to Rapa Nui, that fed on pollen and nectar (cf. Robinet et al. 1998). The parrot is believed to have been an important pollinator of the *Jubaea* palms (Diamond 1995, Van Tilburg 1994). The rats also probably destroyed palm seeds (Diamond 1995) and thus would have had a severe two-fold impact on forest regeneration. When the palms and one other forest tree species disappeared, the people could no longer make canoes to get fish, and thus lost their main source of protein. The cultural decline that followed may therefore have resulted more from disruption of both pollination and recruitment of tree species by invasive rats than from direct human over-exploitation of forest resources.

How credible is this hypothesis? *Rattus exulans*, *Rattus rattus* and *Rattus norvegicus* are responsible for more island extinctions than any other predators. These rats feed on eggs and chicks of birds nesting on the ground and in trees. We know that they have wiped out bird species on 26 islands. On the Hawai'ian islands, Midway Island, Lord Howe and the South Cape Island, rats caused abrupt waves of extinction that eliminated many native bird species simultaneously. Introduction of herbivorous mammals on islands may also cause the rapid extinction of native plants. On Phillip Island, introduced pigs, goats and rabbits caused the extinction of 13 plant species, including two endemics. On Laysan Island, rabbits wiped out 26 plant species in 20 years.

We have heard that habitat destruction and fragmentation is the most important cause of biodiversity loss in the world. Invasions by exotic species are the second most important cause. And a huge proportion of those extinctions occur on islands; 93% of recently extinct species of amphibians and reptiles, 93% of birds, and 29% of mammals lived on islands. Invasive exotic species are the chief threat to more than 90% of the native species on Hawai'i.

In some islands, the situation is becoming desperate. Introduced mammals, including rats, cats and pigs, have caused 64% of frogs and lizard extinctions and 75% of known bird extinctions on New Zealand. In Hawaii, around 45% of the flora is now exotic. Local conservation efforts to save a large proportion of native species have had to fall back on the installation of strictly guarded exclosures to keep out feral pigs and goats and to try to prevent further expansion of populations of the rosy wolf snail *Euglandina rosea*.

In an even more dramatic case, 75% of the islands Tahiti and Moorea are now covered by *Miconia calvescens*, a tree introduced from tropical America. As a result 50% of the native flora is believed to be endangered. Educational campaigns are primarily focused on preventing *Miconia* from spreading to other islands. The consequences for ecosystem services and the economic impact of this dramatic vegetational change have yet to be estimated, but will certainly be enormous.

Why are island ecosystems so vulnerable and prone to invasions? Scientists do not yet agree on an answer, but there are several possibilities. Firstly, islands tend to have fewer species than equivalent areas of mainland, and this may mean that there are yet many unoccupied niches available for invading species. Secondly, isolation may tend to relax competition, and over evolutionary time, this may mean that island species tend to become inferior competitors. Thirdly, when an alien species arrives on an island, it may experience “ecological release”, which arises when the species in its new environment finds itself free of parasites, diseases, predators or herbivores. Finally, islands are often crossroads for intercontinental trade, and the rate of introduction of potential invaders may be higher than in most mainland areas.

Can we predict which species will prove to be successful invaders in particular communities? So far it has proven difficult to identify characteristics that might distinguish potentially invasive from benign, non-invasive, species. One approach is to look at the natural ecology of the species and try to use what we learn to see how favourable the new area might be for the species. Another is to try to compare biogeographic characteristics, or to look for taxonomic patterns in invasiveness.

Our perplexity is not new: Darwin recognised it in 1859, when in the “Origin of Species” he noted that “If all the animals and plants of Great Britain were set free in New Zealand, in the course of time a multitude of British forms would become thoroughly naturalized there, and would exterminate many of the natives... Yet the most skilful naturalist from an examination of the species of the two countries could not have foreseen this result” (pp.337-338).

Any robust theory that leads to the prediction of whether a species will invade successfully must account for the cases of apparently benign alien species that have been present in a new area for decades, but suddenly become invasive. Although scientists may be able to explain this phenomenon *post hoc* and case by case, so far it has proved impossible to pin down any pattern that could predict such a dramatic change of ecological behaviour.

There is, however, one pattern that frequently recurrs: the vector that encourages the spread of an introduced species is often itself an introduced species. Immigrants frequently help one another to invade. Whatever may make it possible for an organism to invade, invasive species often interfere with the functions of ecosystems and with their processes. Frequently they dramatically alter disturbance patterns or modify successions.

The impacts of invasions are not easy to assess, partly because there is always a time lag between the arrival of the new species, the first hints that it will become invasive, and the first impact and ecologically or economically noticeable effects. Part of the difficulty also stems from our current lack of understanding of the value of goods and services from intact ecosystems, and it is therefore very difficult, if not impossible, to quantify the effect of the invader. In some cases, the only thing we can easily quantify is the cost of control of the invasive species, which can be enormous. On the other hand, the invasive species may also bring with it economic advantages to some people, if it can be used to make something, to feed to livestock, or to eat. An example of this is given by the infamous water hyacinth, which while being a hugely problematic pest in many tropical waterways, provides essential income in some communties where it is exploited as a source of fertilizer, biogas and, in some cases, a raw material for local handicraft industries.

Experience shows that it is, to all practical purposes, impossible to erradicate most invasive species. Practitioners no longer talk about erradication, but control. There are really only three options: mechanical, chemical, and biological control.

Mechanical control normally means physically destroying or removing individuals of the offending species, sometimes by machine, but often by hand. Expensive and usually labour-intensive, it is frequently the only realistic option open to impoverished farmers or conservation authorities.

Chemical control means poisoning the individuals. Ideally the chemical is only toxic to the target species, and breaks down harmlessly on contact with the soil, but often broad-spectrum toxins are used. Not only is this a rather expensive solution, but the control of the alien can also damage the environment or pollute water supplies.

Biological control works by subjecting the invader to competitors, predators, parasites or pathogens. The biological weapons must be specific to the invasive species and must not be able to live on other organisms in the invader's new environment, or they may well become dangerous invasives in their turn. This implies intensive research to study the invaders in their natural environment to find weak points in the life cycle of the species and to identify its natural enemies. After this initial identification must follow extensive, costly tests to ensure that these natural enemies are sufficiently host-specific to attack only their intended target.

The 3rd meeting of the Conference of the Parties of the Convention on Biological Diversity encouraged the Scientific Committee for Problems of the Environment (SCOPE) and its partners (UNEP, IUCN, DIVERSITAS and CABI Bioscience) to develop a strategy and plan to deal with harmful invasive species. This led to the formation in 1997 of the Global Invasive Species Programme (GISP) to develop ways to deal with exotic invasive species. GISP is funded by the Global Environmental Facility, UNEP, UNESCO, the Norwegian Government, ICSU, NASA, la Fondation Total, the Packard Foundation, and the John D. and Catherine T. MacArthur Foundation.

GISP will draw together the best management approaches for pest prevention and control and make these readily accessible to all nations, and lay the groundwork for new tools in science, information management, education, and policy. It has three main threads to its work: (1) to establish a global early warning system through a global data base linked to the CBD Clearing House Mechanism (CHM) and to the Global Biodiversity Information Facility (GBIF); (2) to examine how trade acts as a vector for invasive species; (3) to establish new approaches to analyse the risk of extinction.

Its work is not without powerful opponents, unfortunately. The World Trade Organisation is not in favour of one of GISP's initiatives – to establish a "white list" of organisms that have been found to be non-invasive.

All this may seem rather depressing and hopeless, but islands have some reasons for optimism if the resources are provided. Immigration can be controlled, and invadors can be detected. Erradication is diffcult, but it has succeded on some island invaders, and the spread of invaders can sometimes be halted. Resources could also be directed to rescue operations for endangered species, turning some islands into Noah's Arks of endemic endangered species.

Furthermore, we can recommend that islands adopt a view of management that is adaptive. Policies can be implemented as experiments, which, if successful, can be pursued, but if not, can be modified. This means that we should encourage ecological management in islands that includes actions to monitor the responses of ecosystems as human behaviour changes.

There are so many things that we do not know about invasive species that it is difficult to pinpoint just a few research priorities for invasive species. The questions that seem most urgent are:

Why are island ecosystems so vulnerable and prone to invasions? In general terms, what makes an ecosystem invasible?

What makes a species invasive? Can we predict which species will prove to be successful invaders in particular communities? If so, can we develop effective screening procedures that will tell us how likely it is that a species will become invasive in particular environments?

Why do hitherto benign species suddenly become invasive?

Can we model invasive spread, both in homogeneous and heterogeneous environments, perhaps based on existing models of the spread of epidemics?

Can we predict the impact of invaders on other organisms and ecosystems?

Can we formulate a general theory of biological invasions?

Perhaps we can summarise these questions into three priorities:

1. Monitoring, modelling and predictions of the behaviour or invasive species.
2. Tests to control invasive species using appropriate control and evaluation.
3. The establishment of a philosophy of modifying policies and practices in the light of experience – the experimental approach to the implementation of policy.

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Questions and answers

To what extent does the Global Invasive Species Programme encourage or fund scientific research? (Christian Paterman, DG RTD, EC)	There is no direct encouragement of research in the programme, but there are efforts to implement centres for the study of the biology and mechanisms of invasive species. In the US and Australia there are some major actions. For example, President Clinton has asked for a research effort to contribute to the battle against invasive species.
Invasive species sometimes possess a particular syndrome of characteristics, or part of the set. In the case of invasive plants, they can often fix nitrogen, have large leaves, are tall, and start their vegetative phase earlier than other vegetation. They may also have characteristic seed size, and often exhibit fast growth. Could we not use such a suite of characteristics to predict the probability that a plant will be likely to become invasive?	It is true in some cases, but in a large proportion of invasive plants it would not have been possible to use such characteristics to predict that they would become successful invaders. To develop good predictive ability, we must find ways to incorporate knowledge on the biology of the species and on its natural habitat, as well as interactions with local biota.

(Giselher Kaule, University of Stuttgart, DE)	
Madeira has a programme for the restoration of the Desertas Islands where the objectives are to eliminate invasive plant species. Also in Selvagens Islands there are programmes to eradicate invasive species. (Suzana Fontinha, Jardim Botânico da Madeira, PT)	
The GISP will evaluate models for the control of invasive species that could perhaps be adapted for genetically modified organisms (GMOs). Is there any experience on this topic? (Stefan Vetter, Min. for Agriculture, Forestry, Environment and Water Management, AT)	In fact it is rather the other way around. Given the economic and political importance and interest of the subject, more modelling has been done on the possible spread of GMOs than on "natural" (unmodified) invasives. GISP feels that these models, developed for GMOs, may prove very useful in the case of natural invasive species. In the future, perhaps we should encourage legislation to ensure that the horticultural importer of species from elswhere must carry out research to determine the potential invasiveness of the imported species.
Yellow Ginger (*Hedychium flavescens*) is a native plant of India and Madagascar. Here in the Azores, it has been called "an almost insuperable scourge", and indeed yesterday we saw entire hills covered with this plant. Other hillsides are covered with bracken (*Pteridium aquilinum*). Would you recommend to the Azorean Government that they should find out whether a programme of biological control might be used on these invasive species? (Martin Sharman, DG RTD, EC)	Yes, but the government should not expect that results will come easily. Biological control is not be easy to achieve because of the complexity of the problems, and especially the need to be sure that the control agents do not themselves get out of control and become a scourge in their turn.
You told us that some alien species are for a long time not invasive, but then suddenly become so. Could this be triggered by climate change? (Jan Kirschner, Institute of Botany, CZ)	There are many examples of such delayed invasiveness. Some times the mechanisms are known, in other cases the change in behaviour is mysterious. Particular weather patterns may sometimes be suspected, and for this reason we might think that climate change is perhaps sometimes a cause, though there is often not much evidence for this.
Is there knowledge on habitat characteristics that make them more (or less) vulnerable to invasions? (Simone Matouch, Network for Environmental Research, AT)	As is so often the case with invasive species, information is lacking, and sometimes contradictory, or conflicts with what we would expect theoretically. For example, we would expect that habitats in which biodiversity is high should be more resistant to invasion, but we know of cases where they have been invaded.
Long-term research is needed to respond to some problems that cannot be addressed	Yes, I agree. Biological cycles and especially ecosystem cycles, and the process leading to

with 2-3 year projects. For instance, EU regulations that impact the environment in one way or another should always be accompanied by funds dedicated to long term research that will assess and evaluate the effects of the policies on biodiversity. (Francisco Moreira, Centro de Ecologia Aplicada, PT)	invasions, and the cycle of invasion, are often so long that we cannot do much in 2 or 3 years.

Islands in an ocean of diversity

David Billet - Southampton Oceanography Centre, United Kingdom

The difficulties of working in the marine environment, particularly the deep sea, means that there is no easy way to inventory or study marine biodiversity, and for this reason very little is known about the marine biodiversity near islands or in the deep water around sea mounts. Furthermore benthic (seabed) and pelagic (water column) biodiversity are driven by different factors, and deep-sea and shallow water systems operate in different ways. Most of this talk will focus on the biodiversity of the deep ocean, and in particular on the ocean bed, or benthos.

Marine systems are different from terrestrial systems in a number of ways. The environment is essentially three-dimensional by contrast with the terrestrial environment, which for most species is largely two dimensional or at best two-and-a-bit. In this respect the nearest equivalent in the ocean to the terrestrial environment is the benthic surface. Marine organisms often have complex life-cycles in which various life-stages may be quite unlike each other in shape, size and behaviour. This complicates identification and taxonomy. Marine systems are open, in that they have significant possibilities of connection between populations. For example, the deep-water coral *Lophelia pertusa* is found all the way from Spain to northern Norway. Most of the world is covered by deep ocean, and this means that there is a vast amount of the globe whose biodiversity is essentially unsampled.

Humans cannot breathe unaided underwater, and cannot survive the pressure at even quite moderate depths, and so must seal themselves off from the environment that they want to study. This adds considerable expense and logistic difficulty to scientific research. You need a ship to get to the middle of the ocean – again with considerable cost and logistic complications. The problem of understanding marine biodiversity is large-scale in this straightforward geographical extent, as well as in other more figurative extents. It is unlikely that we can use the same approach for the study of biodiversity in marine and terrestrial systems, or even, for that matter, in shallow and deep marine systems.

Our understanding of deep ocean biodiversity is limited – indeed, by comparison with the size of the task that remains, one might almost it is say virtually absent. In this respect it is significant that we have only very recently found out that the deep ocean is in places physically dynamic, with strong currents and seasonal effects. South of the Azores there is very little seasonality, and most of the nutrients drifting down from the surface are consumed in these warm waters before they reach the sea bed. In the colder northern waters, by contrast, climatic imbalance and the stirring of surface waters allow nutrients to escape and to sink right to the sea floor. The sedimentary environment is not just featureless mud, but is surprisingly heterogenous both in space and time. Species move from deeper to shallower water in response to climate change, as will be seen later in this presentation. In a decade, the density of species at a given site can triple or be cut to a third. We now know that in places of tectonic activity, hydrothermal vents support extraordinary organisms in extraordinary diversity.

<u>Why is marine biodiversity important?</u>

The deep sea may seem as remote as the surface of the moon, but it has impacts on many of our lives in Europe. Many oceanic organisms play key roles in regulating or driving essential biogeochemical processes, not least the global carbon cycle. Inversely, envrionmental change affects marine biodiversity, which means that measuring changes in the diversity of biological communities is a useful method for assessing environmental change. Knowledge of natural levels of biodiversity and the processes regulating natural change are essential for formulating good environmental policy.

<u>Threats to marine biodiversity</u>

The list of threats to marine biodiversity will seem familiar to anyone who has encountered such lists for terrestrial organisms: chemical pollution, eutrophication, invasive species, injudicious harvest or over-exploitation, and global climate change. Added to these familiar threats, organisms living in the sea are also threatened by the exploitation of deep-sea oil and gas resources, and deep-water fisheries in European seas. These activites must be managed in a way that can be sustainaned without environmental damage.

On the basis of what little information we have, it seems probable that communities on the sea bed, once disturbed or destroyed, may take many decades, or conceivably many centuries, to recover.

Benthic biodiversity

As we move deeper under the surface of the ocean, biodiversity typically increases for the first 2000 metres. After that, it starts to fall off. The reason for this distribution of diversity is not well understood.

The oceans cover 360 million square kilometres, but only an area the size of a few football pitches has been sampled for macrofauna (polychaete worms, bivalve molluscs and crustaceans) and considerably less for meiofauna (nematodes and foraminifera). A deep-sea sediment sample covering a quarter of a square metre will typically contain about 100 macrobenthos species, 100 species of nematode worms and 200 species of single-celled foraminifera. Depending on the location and the faunal group, 50 to 95% of these species will be new to science.

The relationship of this high local diversity to global diversity is controversial. The problem is that the number of species rises steadily, indeed almost linearly, as the area sampled increases, without the slightest sign of a plateau. Some scientists guess that there are half a million benthic species, but these researchers seem to be a conservative minority. More frequently we see guesses of about 10 million macrobenthos species and perhaps 100 million meiobenthos species. The number is open to question, and perhaps all we can say with certainty is that we will not soon know the truth. Whatever it is, the number of species living in, on, or just above the sea bed probably dwarfs the 1.7 million species – from all environments on Earth – that taxonomists have so far described.

It is important to relate local biodiversity to regional and global biodiversity, not simply because we are curious about the number of species, but because as physical scale changes, so do the factors that influence and determine biodiversity.

Pelagic biodiversity

The midwater realm is believed to support fewer than 200,000 animal species (of which about 20% are undescribed) and 4000 marine plant species. As with benthic systems, however, local diversity can be high, and pelagic systems play a key role in many oceanic processes. Diversity is not a measure of ecological relevance.

Biodiversity on island slopes, seamounts and abyssal hills

Oceanic island slopes and seamounts are difficult places to sample and their biodiversity is poorly known. Although there is considerable scope for further work, the few studies suggest that most species are widespread or cosmopolitan, with only about a third endemic. Seamounts and islands might also act as stepping stones for transoceanic dispersal of species.

Key environmental variables regulating species distributions

Apart from latitudinal effects on biodiversity, water masses influence the distribution of deep-sea organisms either directly or by acting on the distribution of larval stages. Topography and its interaction with currents, internal waves and other physical oceanographic processes are also key factors. Changes in the flux of organic matter from surface waters to the deep-sea floor have important effects and may cause the inter-annual, and perhaps decadal, changes noted in deep-sea ecosystems. A species may be found everywhere in an ocean basin, but its bathymetric range may be constrained to only a few hundreds of metres by environmental variables that change with depth, such as temperature and pressure.

Deep-sea biodiversity and climate change

Recent work on the diversity of fossil ostracod shrimps and the single-celled foraminifera suggests that the deep-sea benthos has been sensitive to environmental changes linked to climatic oscillations occurring on time-scales as short as decades to centuries. The deep-sea benthos has also shown fluctuations linked to glacial cycles. The onset of anthropogenic global warming heightens the need to understand the impact of these rapid climatic oscillations on deep-sea communities. There are decadal-scale changes in marine systems related to ENSO events and the North Atlantic Oscillation which require a long-term research plan beyond the scope of present European projects (typically lasting no more than 3 years).

New technology for ocean biodiversity research

New technological developments in Autonomous Underwater Vehicles (AUVs) and Remotely Operated Vehicles (ROVs) will allow new high-quality samples to be taken in difficult environments, such as on the steep slopes around oceanic islands, on seamounts, and under ice shelves. The equipment used can significantly influence the number and types of species collected in a sample. Hydraulically-damped corers should be preferred over impact corers to sample sediment since they collect twice as many animals.

New technology (ROV and AUV) will allow us to overcome many of the problems of sampling in deep-water, but it will take a lot of time to take sufficient samples to address the fundamental questions in marine biodiversity. To get answers quickly will need to good planning of European effort.

Research priorities

A long-term European-wide co-ordinated research programme is needed for the study of the biodiversity of terrestrial, shallow-water and deep-sea environments (including oceanic islands). Separate research plans are required for deep and shallow water.

The first priority of any such plan is for more data, collected at a regional scale, using standard methods for sampling, analysis and taxonomy – and the first step is to agree on those standards.

We need European-wide expertise in marine taxonomy.

What natural processes cause the biodiversity of the ocean bed to change?

Can we distinguish natural and anthropogenic drivers?

How do oceanic islands help to preserve biodiversity?

http://www.soc.soton.ac.uk/GDD/DEEPSEAS/

Questions and answers

Are there enough taxonomists to deal with the marine biodiversity recently discovered? (Stefan Vetter, Min. for Agriculture, Forestry, Environment and Water Management, AT)	No. As in many other areas of biodiversity, our understanding of marine biodiversity suffers from the taxonomic impediment. We as a community must define priorities, and morphologists and taxonomists must set to work on a planned attack on the problem. Molecular taxonomists will certainly have to be called in to solve some of the problems that we face.
Do you agree that tradtional taxonomy is at least as important as molecular taxonomy? (Ana Neto, University of the Azores, PT)	I do not want to say one is more or less important to the other. Whether the taxonomy comes from external morphology or genetic studies is not really that important.
Taxonomy is not just research. It is the quality control system for biodiversity. (Mark Costello, ECOSERVE, IR)	Yes. I would also like to counter the belief that most taxonomists are close to retirement. There are many trained students, potential taxonomists, in our European laboratories. The problem is that there are very few jobs, and wonderfully limited career

	prospects, for a taxonomist.
It is significant that taxonomy appears in the 5th Framework Programme, because up until this programme, Member States have considered that taxonomy is their responsibility, and that it is not a proper topic for Community research. Indeed, taxonomy is not widely recognised as research. We must do whatever we can to change people's views on this. Taxonomy is a science, and it is work that gains value by being done at Community level. (Christian Patermann, DG RTD, EC)	
Many marine species have planktonic gametes, eggs or larvae in their life cycles, which are carried away by oceanic currents, sometimes to great distances. These characteristics of the life cycle of marine species and their interactions with oceanography are mechanisms of dispersal – with implications for population dynamics – that may be specific to the marine environment. Do these deep-water species also have a planktonic phase in their life cycles? If so, has larval dispersal in deep-water species ever been addressed? (Henrique Queiroga, Univ. de Aveiro, PT)	Yes. In our studies it appears that certain areas are colonised from larvae that originate in upstream areas.

Species survival in fragmented landscapes, human impact and its mitigation

Giselher Kaule - University of Stuttgart, Germany

Islands may be surrounded by water. Metaphorically, they may be secure habitats, or refuges surrounded by land turned over to a use that is inimical to most wild species. Examples are nature reserves, with associated buffer zones, in which input tending to disturb the ecosystems, such as nutrients and invasion of competing species, are controlled by human intervention. Other examples are dry grassland hills in landscapes dominated by agriculture, rocks in a large forest area, or lakes in a plateau. In each case, the species inhabiting the habitat finds itself living on an island, from the point of view of its requirements.

If we can use the concept of the island to describe these isolated habitats, then we can also adapt the models used in real islands to look at the survival of isolated populations. Experiments show that the likelihood that a species will survive can be identical in a single large habitat or in several smaller island habitats, provided that the islands are sufficiently connected, from the point of view of the species in question.

Oceanic islands are subject to tides. If the water between two islands is sufficiently shallow, then at low tide they will be joined by dry land. Connectivity increases. This tidal model of connectivity can be used to consider what happens to habitat islands in years that are optimal for the population in question. In these good years, marginal habitats in the natural matrix of habitats near the islands become acceptable, and not only does the size of the population increase, but so does the interchange between previously rather isolated populations. Furthermore, migrant individuals have a better chance of travelling further, finding suitable uninhabited habitats, and colonising them.

In bad years, extreme high tide drowns all but the highest islands. In other words, the quality of previously suitable habitat becomes sufficiently poor that the species can no longer survive there. The only survivors are those in the habitat of highest quality, now possibly itself become sub-optimal. When conditions return to normal, the species can once again spread from the few refugia, and re-colonise its previous habitats.

This reduction and expansion in the range of a species is part of the stochastic dynamic of landscapes, and has occurred throughout the existence of life on Earth.

Humans have blocked this natural cycle for many – perhaps most – other species. In modern landscapes human economic activities have led to habitat destruction and fragmentation. In terms of the analogy, the degree of isolation of habitable islands and archipelagos is increasing, in a one-way process. The network of human infrastructure and intensively managed land is stable and permanent, in sharp contrast with the hitherto dynamic biological processes. At the same time those economic activities have changed the matrix between suitable habitats into an increasingly inhospitable waste for most species. The ocean itself becomes increasingly impassable. The survival of the population becomes questionable as meta-populations find themselves permanently isolated from all others of their kind. There are no good years any more. The stepping-stones between refugia are obliterated, sunk forever under the ocean. There are bad years, and there are worse years. In years in which normal variation (e.g. in weather) exerts extreme natural pressure on species, the consequence of human activities can add yet more difficulty for the survival of the species. This explains some of the phenomena of biodiversity losses in modern landscapes.

Agricultural land in our industrial society is not at all the same as it was in the more agrarian past. In the past, non-agricultural species were quite well represented in hedges, woods or uncultivated patches amongst farmed land. Thus, for most species, the typical community was of much higher quality than it is today under the intensification of agriculture. Furthermore, the farms themselves were not the hostile places that they are today. Fertilizer, pest control and stock stabilisation has eliminated biodiversity, forming barren land for most organisms. An industrialised farm is a sterile, sometimes even a toxic environment for most species, and these sterile areas have covered more and more land. As a result, the remaining habitats for wild species are increasingly isolated from one another, scattered island refugia in a hostile ocean of arable land.

Unfortunately there are some additional dangers in our industrial agriculture. It is not easy to predict the weather, and farmers will tend to over-fertilize, in the hopes of good weather for their crops. In a good year, the crops can use all the fertilizer that the farmer applies. But often, the weather is sub-optimal, and the farmer turns out to have been optimistic. In this case, the crops cannot use all the fertilizer, which then runs off, or seeps into the water table, polluting the environment. The pollution may be toxic to some species, while to others it may encourage growth, sometimes provoking detrimental blooms of those species. At the moment the EU production quotas encourage farmers to aim for the highest possible yields, and therefore to over-fertilize land. The policy should be re-thought so that farmers are encouraged to aim at a yield that can be sustained. This would often mean aiming to provide enough fertilizer that the yield is not depressed below the basic yield, determined by an ecologically sound yield that can be achieved in a normal agricultural year.

The island theory and the tidal model of connectivity does not explain all causes behind biodiversity losses, but they are helpful to understand many phenomena. In particular, they help us to focus on the importance of the improvement of the quality of the matrix between habitat islands, and the fact that the land use of the matrix must be integrated into the system. In addition, the tidal model shows that where possible, mitigation measures should be undertaken to restore conditions that will allow the natural dynamic processes to start again.

For example, this implies that conservation strategies such as the Flora-Fauna-Habitat (FFH) reservation system of NATURA 2000 are incomplete unless they act to improve the quality of the habitat between the protected islands. These intermediate lands, which are dominated by agriculture and fragmented by infrastructure, should contain managed areas where economic production is carried out while maintaining sub-optimal habitat qualities for as many species as possible. These sub-optimal habitats will form biodiversity highways or stepping stones for normal migration and population exchange, and might include flooded plains, forest belts, or sheep transhumance corridors.

To allow species to recolonise habitats, forest edge, field margins and fallow land can provide temporary but essential paths. They should be managed accordingly, with restraint and sensitivity that may ask farmers and foresters to accept small economic losses from land that is less than fully productive from an agricultural perspective.

In some cases it may be possible to provide wild species some sub-optimal habitats, for example extensively used marginal land, that will serve to buffer stochastic events and reduce the speed of creeping landscape changes. With proper attention, meadows used only in moderation for grazing, forests with indigenous tree species and slow turn-over, and low input arable land can help to ensure the survival of populations by providing temporary islands in unusually good years.

Today, European and national legislation requires those responsible for major new infrastructure, such as motorways or railways, to examine the potential ecological impact of their project and to make sure that the negative environmental effects are as small as possible. Unfortunately, the quality of the databases that are exploited to study the ecological impact is often at best dubious, even for some hugely expensive infrastructure projects.

It would be possible to cite many examples of environmental impact studies that do not take these ideas into account. It is possible to show that models will suggest one solution if direct habitat losses are considered, but quite a different solution if both habitat loss and connectivity are borne in mind. In one practical case, for example, a study was conducted of alternative routes for a highway north of Halle (Sachsen-Anhalt), using the Blue-Winged grasshopper *Oedipoda caerulescens* as a target species. The worst of 5 alternative routes, when the potential losses of connectivity were considered, had been second to top when habitat loss alone was taken into account.

It is important to select the right species in examining the potential impact of an infrastructure project. Since different species have different needs for connectivity, their characteristics must represent a wide range of other species. For example, in studying ways to mitigate the impact of a highway through dunes and flood plains, it would not be possible to select a single target species.

The needs of the otter (*Lutra lutra*) can be taken to represent species living in rivers, and riverside ecosystems or flooded plains. They have large home ranges and can migrate over long distances. The requirements of the corncrake (*Crex crex*) are quite different. It needs extensive wet grasslands, and exhibits wide fluctuation in population size. This leaves the sand dune grassland, characterised by a high percentage of bare sand; for this habitat, a grasshopper (*Stenobothrus lineatus*) is a useful target species. It needs extensive grassland, and high connectivity of habitats.

By looking at the needs of these three species in a simplified model of a more complex plan we can see that the location of the highway could easily cause one or the other to suffer. A route that took the road through tunnels that pass under the dunes would protect the sandy ecosystems, and satisfy the grasshopper, but where it crossed the flood plains it would interrupt the migration routes of the otter and disturb the corncrake. By placing the road high on the dunes, crossing the floodplains on high bridges, the otter would benefit at the expense of the locust. All three species find a compromise when the road runs over the floodplain on a medium altitude bridge but cuts through the dunes, where it is covered from time to time by artificial green bridges. Species like the corncrake also need an extensification of the grassland in the landscape matrix.

http://www.ilpoe.uni-stuttgart.de/team/gk/kaulecv_en.html

Questions and answers

We can deduce and predict the impact of our actions in some cases. Science, however, usually refuse to deduce from what is to what should be; in other words, it refuses to be normative, or to suggest rules governing human activities. But scientists are human beings, and one of the characteristics of our species is that we make decisions about what should be. Should science be normative and propose models for development? Can landscape science say how things should be to fit best the requirements of biodiversity? (Broder Breckling, Univ. Bremen, DE)	Science and scientists may not be normative, but engineers are. And in practice, scientists often take a normative view. For example, one could imagine a concerted action that aims to harmonise methods and models. That is normative. In conservation work, scientists are more or less forced to be normative. They first agree amongst themselves and with the other stakeholders what landscape we want to have, and then devise methods to measure how different things really are. Then they seek ways to reduce that difference. In short, science should sometimes be normative. Its practitioners should be ready to propose mitigation measures and devise ways to minimise impacts.
You said that projects are often based on rather shaky data. Are there examples of infrastructure projects where follow-up studies have been done to monitor the effect of the mitigation measures that were implemented? (Martin Sharman, DG RTD, EC)	This can be done, and some big projects have set aside money to look at how the mitigation actually works. Sometimes, one can successfully use the argument that the existing data are insufficient, and so justify additional studies. In most cases, however, the data covering the situation both before and after the project are so poor that it is really very difficult to monitor anything – or rather, to say what the impact of the mitigation attempt really is.
You have shown that we should use target species to examine the effect of different infrastructure development models, when we lack more comprehensive analyses. But are the species we select good indicators of change and impacts? Do we really know what these species indicate? Don't we need better assessment of the relationship between these species and other elements	I should first point out that the species I used as examples here are only a small sub-set of the array we use in reality. I picked these three species just for illustration. In fact, we do not really know what the species indicate, and for this reason we use a wide range of species of a great variety of types. We must also be careful not to use certain indicator species just because they best demonstrate our own

of the ecosystem before we can extrapolate our models to total biodiversity? (Tor-Bjorn Larsson, Environmental Protection Agency, SE)	preconceptions. To avoid this, we have compiled a "target species" list across the whole state. This list includes important species in all habitats, and can be used as a reference list from which to draw particular sets of species for each project. The Flora-Fauna-Habitat (FFH) species and habitat lists work in the same way on European level. I agree that to analyse impacts properly we must have a good knowledge of the ecosystem, including its components and its processes. And we also need a similar of understanding of the species involved.
I would like to come back to the interesting discussion on whether this is a normative science. I do not think that it is. Even the simplest natural ecosystem is astonishingly complex. Any useful model is a greatly simplified version of nature that you adapt to the observed system and use to generate predictions. This does not imply that it is normative. (João Coimbra, CIIMAR - ICBAS – Univ. Porto, PT)	As long as our understanding of ecosystems and our knowledge of how they work is not good, there is little alternative to taking as many bioindicator species as possible. We start with 360 important species, which we think gives us a buffer of security. Perhaps the number is too high, but we have not been able to finance the research that would be needed to reduce this number.