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BIODIVERSITY MATTERS

$$V_{mp}(L) = \{N_R \cdot p \cdot r \cdot a \cdot V_i / n\} / H$$

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Biodiversity Matter

an extension of methods found in the literature on monetisation of biodiversity

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ENGLISH ABSTRACT:

Biodiversity is an area that is gaining in public interest in these years. The decline of tropical forests has been well-known for some period, and arguments have been made that this destruction should not go on for the common sake of mankind. But how to argue more seriously that the biodiversity in those areas should be protected?
This paper tries to give an answer in that it investigates possible applications of natural biodiversity, but also from diversity found in indigenous agricultural systems, where not the loss of species but "only" of varieties of common food crops is important.
Starting with a description of the topic of biodiversity loss, taking place in these years, and putting the subject in perspective, the text uses an ansatz published in the literature on medicinal use of tropical natural biodiversity, and extends it to also cover other possible applications.
A monetary value is given for a species and also an area related ratio for different regions of the World. It is shown that the commonly used argumentation of the vast medicinal potential of tropical biodiversity pales against other possible applications.

The text contains a table of contents, an index of tables and figures, and a literature list where the reader can find background literature used for the paper.

ABSTRAKT:

Biodiversitet bliver stadigt mere behandlet i disse dage. Teksten forsøger at besvare spørgsmålet, hvordan man kunne sikre den naturlige biodiversitet, ved at bruge en antagelse for at beregne den værdi, som tropiske planter har for mulige medicinske anvendelser, en tilgangsmåde, som er blevet publiceret for nylig.
Ud fra en almen beskrivelse, af hvad biodiversitet egentligt betyder, forsøges at bestemme gennemsnitsværdien af specier eller arealer for forskellige regioner i Verden. Der vises, at den tit fremhævede værdi, som tropiske planter skulle have for medicinindustrien, blegner over for de andre anvendelsesmuligheder af biodiversitet.

Teksten indeholder en indholdsfortegnelse, en opgørelse over afbildninger og tabeller, og en liste over den benyttede baggrundsliteratur.

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Introduction

Biodiversity is related to the loss of species, but it also implies the services that we get from ecosystems. As one example of species loss we can mention corn cockle, *Agrostemma githago*, that formerly was very feared in wheat fields due to its poisonous grains. It is now included in the red list in Germany under *Gefährdungsgrad 1* (Schauer and Caspari, 1993, 62), which means that it is "threatened by extinction so that its survival without protection measures is very unlikely". Exactly this plant was recently rediscovered as a possible candidate for biomass production and as a source of medicinal and industrial raw materials (Nørgård, 1995) or a natural biocide for seed protection (Beringer, 1996).

This variety of the plant's applications exemplifies the services that we may gain from biodiversity. Another example could be the cleaning of waste water by natural wetlands, a service that is performed for us by natural wetlands, as described in Turner *et al.* (1995), saving us extra energy input and economic costs. At the same time such locations can be touristically attractive and attract an amount from our willingness to pay to keep such resorts.

The irreversible loss of diversity is one of the most challenging problems that humanity faces. Had corn cockle been extinguished its comeback could not take place now. This would mean loss of economic revenue and marginal profits when a new species provides new services or existing ones at a better cost ratio. This is the basic argument for looking at what the loss of biodiversity brings about for humanity.

In medicinal use plants might not only be interesting in their probably direct use, like components directly synthesised in a plant, but also as lead compounds (Aylward, 1995, 98). In the latter case chemical compounds are found in plants that direct research to modified substances with better activity ratings.

So despite recent trends to argue for "rational" drug design, methods based on micro-organisms have limitations. The chemical structure required for a specific effect has to be known and the relevant genetic code has to be designed, and only some of the plant-based chemicals can be produced by genetically engineered micro-organisms. Patenting substances alone does, therefore, not automatically guarantee revenue, you also need to be able to produce them to skim the cream (Pearce and Moran, 1994, 102-103).

Very often lead compounds gained from ethnobotanical collections display significant chemical activity at competitive rates (Sheldon and Balick, 1995, 58-59). But this wealth of information is threatened. Ethnobotanical knowledge is rapidly eroding, caught between the loss of species and the habitat that provide new material; especially as indigenous communities and relatively unscathed ecosystems overlap with marked regularity, as they have been relegated to remnant parcels of land, and indigenous people consciously foster genetic diversity within species (Sheldon and Balick, 1995, 52-57).

Despite the obvious wealth of genetic information in plants[1] as possible leads in pharmaceutical applications, plant diversity also has importance for further developments in forestry, agriculture, horticulture and gardening, biomass production, medicine industry and raw materials for industrial uses, cosmetics, stimulants, fibres and lipids, insecticides and fungicides (Robinson, 1988, 357; Plotkin, 1988, 111) and detoxification by using gnotobiotic microcosms (Cairns Jr., 1988, 340). The last point means using plant based methods to clean up wastes, *e.g.* poisoned soils, *i.e.* after pipe, or exhaust streams from industrial production lines, *i.e.* end of pipe.

This paper tries to extend a method applied to pharmaceutical evaluation found in the literature to cover other possible applications of natural or indigenous plant biodiversity.

[1] Of course the biodiversity of animals, vira, eucarythes, bacteria or fungi also is an important factor that needs to be taken care of. In fact the fate of lower species is often forgotten, when one talks about biodiversity. Nevertheless we follow this kind of taxonomic discrimination and concentrate here on plants, as they are the easiest to exploit and most directly supplier of services to mankind.

Current Trends in Agriculture

The human diet has become very much restricted since the introduction of agriculture. 75,000 to 100,000 species are known to be edible (Wilson, 1988, 15; Plotkin, 1988, 107) or have been estimated to been used by humans in the history (Swanson, 1995b, 47). Now of those, less than 4 % are widely cultivated (Sheldon and Balick, 1995, 57; quoting Tobin, 1990), and only about 150 have entered the current world of commerce (Plotkin, 1988, 107). So while up to about 3000 plant species might have been covering the needs of the late stone age man (Vietmeyer, 1986), we today rely on a mere fraction of those riches.

With the global movement towards unification of markets and cultures fewer species than ever in the history of mankind serve the basic nutritional needs, despite the fact that the other species could be superior to the widest used crop plants (Wilson, 1988, 15), especially as temperate climate style agriculture is not suitable everywhere so that other species might offer rewards in other regions of the World (Raven, 1988, 121).

The global foodstock market today relies on less than 20 species (Plotkin, 1992, 107). Seven species provide three-quarters of human nutrition (Sheldon and Balick, 1995, 57), and four of them (wheat, rice, maize and potatoes) cover more than half of our plant based diet (Swanson, 1995b, 47).

Standardisation of crops is going on at an increasing speed. Western culture and its dietary habits[2] displace the original cuisine. Together with the genetical erosion in the number of crop plants that are being used, another cultural erosion has been happening, too: the loss of diversified diets. The diet in the Southeast of France still included 250 plant species at the beginning of this century, today the number of cultivated is down to 60. Only 30 make up the bulk of local consumption (Vellvé, 1992, 33).

What also is diminishing is the diversity within one species, the so-called varieties. For example formerly customers could choose between *e.g.* several kinds of apples, today only a handful, or even only the well known, traffic-light, of green *Granny Smith*, yellow *Golden Delicious* and red *Red Delicious* is available on the supermarket shelves.

The loss of genetic varieties has been happening at an increasing rate in the latter years. Several processes interact:

- The spreading of human civilisation into formerly nearly untouched nature has become obvious, an often mentioned example the migration of swidden agriculture into Rondônia, a part of the Amazonian rainforest. Subsistence farmers forced by land degradation or sheer lack of land for their subsistance are leaving their old habitats and invade the rainforest in order to try to improve their living standards slightly (Myers, 1995, 112). This is a result of a lack of land reforms which are politically difficult to realise.
- In richer countries humans invade former natural areas as a result of wrong zoning laws and a lack of regional planning that gives more and more of Nature's resources away. This is often not obvious as in the case of cities becoming gradually more and more agglomerated squeezing the few remaining natural spots, eventually becoming widespread *metropolitana*.

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[2] Sneakers and Coca Cola in plain speek.

- Modern agriculture has been reducing the amount of genetical information by its sheer success. Land races are disappearing at a rapid pace not only in the industrialised countries, but even more so in developing countries. Hawkes (1983, 110) cites the proportion of old, indigenous cultivars contributing to the total Greek wheat harvest falling from 80 to under 10 per cent between 1930 and 1965. Another result of marketing new varieties giving higher harvests than most traditional varieties.
- Legislation does not protect wild biodiversity as patents can only be given to defined varieties. Extending the extent of intellectual property rights to also give protection of biodiversity, even though no research has been performed to exploit it yet, can be an approach to save the last resumes of biodiversity.

Frankel and Soulé (1981, 175 ff.) give a very good description on the importance of the genetic diversity of plants used by man. Related weeds, wild varieties and land races could be used as leads for further breeding success. However, normally breeders tend to rely on own stocks and already developed varieties as these offer greatest success at minimal work effort.

For example all the current (1992) French wheat cultivars are descendants of one folk variety called *Noé*; in Germany most wheat varieties carry either *Carsten VIII* or one other variety in their pedigree (Vellvé, 1992, 44 ff., and Beringer, 1996), and winter barley almost exclusively descents from one sole cytoplasm-sterile plant plasma (Saatgut, 1996, 12). These examples are all signs of a rapid decline in diversity of our crops' genetical material.

But in fact the wild varieties and land races have been the major reason for yield increase in the established crops; about half of which is due to genetic improvements by implementing features from such sources (Srivastava *et al.*, 1996, 5). So any reduction in the availability of such sources threatens further agricultural progress with respect to increasing the yield or implementing immunity to various pathogens.

Nature has otherwise been quite efficient in creating a pool of genetic information that is being exchanged between crops and weeds. One alternative to the current breeder's practice of having only few varieties on which to build their breeding work is the approach ecological farmers have been following. For them reliance on local varieties and on material that is genetically broader than the small ones of traditional farmers is a cornerstone in their work. But there are difficulties. First the supply with seeds from ecological farms is not sufficient so that the farmers might even be forced to buy genetically modified varieties (Bohn, 1996), and there are legal problems in using land races or local varieties, too (Beringer, 1996).

So even though natural selection might lead to low-cost adaptation of the seed material in a region, by inclusion of weed-crop exchange of genetical information, and so transferring natural resistance against pathogens from weeds to the crops, this is not the way agriculture is developing today. But what is a crop, what is a weed?

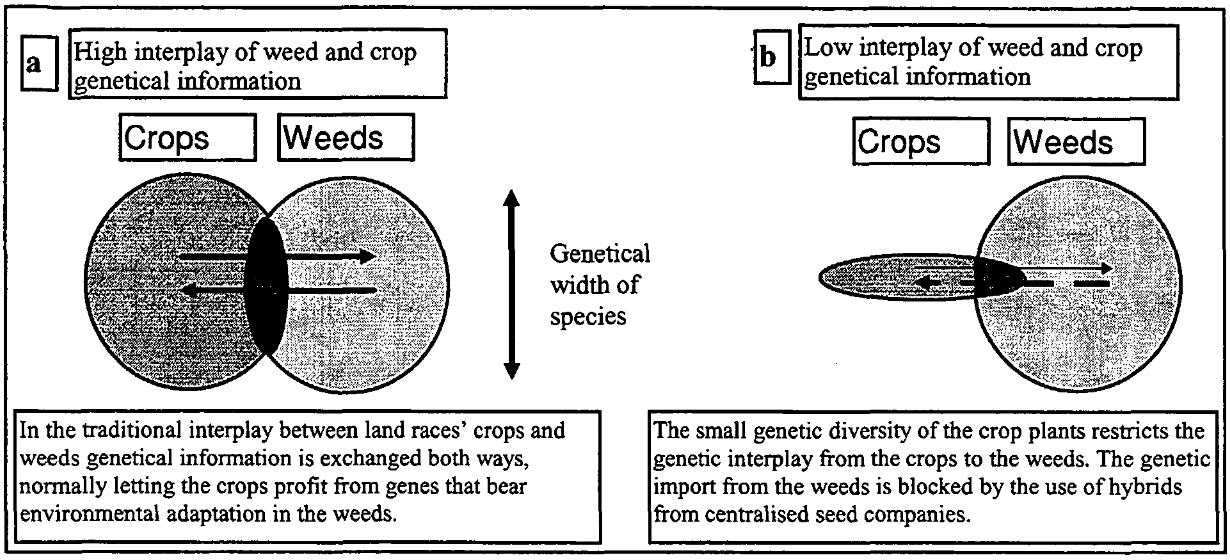
To Weed or not to Weed ?

Nature itself would try to exploit biodiversity in creating new combinations. Several plant species are polyploid, such as wheat, potatoes and sugar cane. There are alternating cycles of hybridisation[3] and differentiation in crops and attending weed races. Gene flow is restricted enough to prevent the total disintegration of distinct crop and weed species but flexible enough to allow exchange of genes between the two groups (Hawkes, 1983, 74).

[3] Hybridization means combining the qualities of two species in a new one.

In principle the process of mutual gene exchange between "weeds" and "crops"[4] enhances genetical richness by recombining qualities and therefore eases the adaptation of seeds to changing environmental conditions, like *e.g.* moving varieties from their original centre of origin (Figure 1). Albeit this coevolution is a bisided sword. By reducing genetical diversity of the crop plants humans also decrease the diversity of the associated weeds.

Figure 1 Comparison between high and low genetical interplay between crops and weeds.



When the weeds cannot interfere with the crop seeds any longer this may seem positive at a first glance – but it has unwanted consequences, too. Weeds are not weeds *per se*. For example rye was a weed in wheat until rye's good qualities with respect to tolerating greater humidity was discovered. Many major cash crops were actually only of secondary interest until other of their qualities were discovered.

What has been happening in Nature, especially in traditional ethnoagricultural systems, is an intimate interplay between weed and crop genetical information, as illustrated in Figure 1. Via the transfer of weed genetical information crops adapt to changing environmental conditions much faster than would be the case otherwise:

- "In many instances whole genomes have been incorporated into a plant by polyploidy (...) Studies of morphophysiological variability demonstrate that cultivated plants have also differentiated into geographical and ecological races (...) also in (...) areas into which they were introduced subsequent to the European voyages of discovery in the fifteenth and sixteenth centuries. (...) the differentiation has been rapid (...) New characters also arise in response to the new selection pressures imposed on the crop in its new environment" (Hawkes, 1983, 75).

As another example of the nearly unnoticed advantage that agriculture gets from natural and genetical interplay, we cite Hawkes (1983, 77) again: "In the circumstances of domestication, then, exposure of plants to different environments and to the varying selection pressures resul-

[4] Depending on your point of view the word weed might mean a weed in one instance and none in other. Rape can be a weed in wheat fields, as can be the opposite.

ting from the changing techniques of farming have caused crop plants to evolve very rapidly indeed. They have also formed natural hybrids with related wild species under conditions and to a degree that would not have occurred at all if agriculture had not taken place. Resistance to the diseases and pests that attack them has also developed in species of cultivated plants. Yet, the increase in numbers of individuals and the fact that they have been cultivated in close proximity have provided conditions nearly ideal for the pathogens. With continual genetic change in the crops, followed by accompanying changes in the pathogens, a remarkably complex picture has built up."

Furthermore the choice of a small number of crops to rely on, and even worse the choice of some few representatives of one plant species[5] for domestication already brings about a restriction of the genetic material because generally in today's intensive, western-style, agriculture much internal genetic variability within this species is being eliminated (Swanson, 1995c, 156). This gets aggravated by the centralised production of plant seeds by a very small number of seed companies that serve the global seed markets (Beringer, 1996).

So when genetical uniformity of crops interact with the weed culture around the fields, the genetical interplay is reduced (Figure 1). The weeds will not be able to give positive inputs, like resistance to pests and against changing environmental conditions to the crop plants. On the other hand, what might be even worse, crops might transfer unwanted qualities to the weeds, like resistance to certain pesticides, a truly unwanted characteristic.

Example: Genetically Modified Crops

The introduction of gene modified rape that is resistant to the active ingredient phosphinothricin, PT, by being equipped with the specific resistance gene, phosphinothricin acetyl transferase (SOU 1995:88), has stirred attention in a row of countries (Abott, 1996), especially as it became clear that this resistance could be transferred to related weed species (Mikkelsen *et al.*, 1996). Demands have been put forward to treat genetically modified plants as pesticides (Wadman, 1996), and there are international complications (Masood, 1995).

The problem here is that a crop also can occur as a weed. As an example rape-seed would be considered a highly unwanted weed in cereal fields. Resistance to a special herbicide then makes it very difficult to root this "weed" out without virtually killing the crops, too.

Another problem might be that the genes in crops that give resistance to a specific herbicide, might be switched off under certain environmental stress without the farmers knowing of this. As one example heat stress might switch off the resistance of a modified plant to one specified herbicide. If the farmers are ignorant about this and use this herbicide in good faith at too high an ambient temperature and application rate they will destroy the complete crop.

This last example, however, is only one of the strange effects of genetical engineering that we know of. Another large problem arises from the large market shares that such genetically modified crop plants might gain. For example glyphosate resistant maize might be widely grown in the future. The biocide can be applied in large rates at those plants, as it is not believed that the substance can percolate into the ground.

What happens, when it becomes known that glyphosate actually can percolate into the ground water, and the market share of both the genetically modified crops and the biocide are large?

[5] In other words a phenotype.

Will it be possible to find substitutes quickly? Will it be possible to clean the ground water, if it needs to be used as drinking water for humans? And what, if the crops immunity against the substance gets transferred to the surrounding weeds?[6]

How, whether, and when genetically modified qualities are spread from the original agricultural system into the natural one, is not known at the present state. It might be that humanity is in for several surprises in that respect, *e.g.* resistance spreading at an even faster speed between increasingly more aggressive weeds[7]. This problem shall not be furthered here.

Forestry

Even worse than in agriculture in forestry, especially over the middle latitudes, geometrical and genetical uniformity predominate following from the long maturing periods of trees and the planning of stands. Greater efforts should be made to protect the still existing diversity, especially the protection of old-growth forests and the essential organisms and processes related to them (Franklin, 1988, 169-174).

Preserving Diversity ?

Diversity is a difficult topic. We can describe the forces that lead to a steady diminishing of biodiversity. But can we not try to protect some of the existing diversity? Genetical diversity on the species level can be conserved in either genebanks or in reserves. Both have obvious problems:

Genebanks

Some plant's seeds can be stored at reduced humidity and low to very low temperatures with storage lives of up to 50 or even 100 years. However not all plants have such orthodox seeds. *Recalcitrant* seeds are produced by "many tropical and subtropical fruit trees and important economic crops such as coffee, cacao, citrus, rubber, and many palms, including oil palm and coconut. Their seeds die very quickly if they are allowed to dry out or cool down toward 0°C (...) The only way to conserve these species at present is through orchard plantings or in natural reserves, and perhaps by means of meristem cultures." (Hawkes, 1983, 123).

It might seem as if diversity preservation solely is a technical problem. But there is more to the story! It is not guaranteed that the possible wealth of genes actually is conserved as has been illustratively described by Vellvé (1992): "it is virtually impossible today to judge whether the seeds held in storage for the future are dead or alive" and quoting Perret (1991) *"Many of the samples may have dead seeds or the holders may lack the funds to regenerate them before the total loss of their viability"*.

Funding and technical problems are major reasons for this dilemma, another simply that being understaffed they cannot fulfil basic documentation needs. Plant seeds are being stored without a

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[6] The reader might ask the question what this presentation has to do with biodiversity? The answer is that this example shows that a reduciton of diversity very well can have effects outside of the immediate area of interest. Such genetically modified crops can be expected to be marketed on a global scale. Therefore they also reduce diversity of crop plants.

[7] Genetically organisms are self perpetuating and permanent. Once created they cannot be recalled Shiva (1993, 107, quoting George Wald)

proper description of the plant's origin, its specific environmental adaptation, current and historical use, and possible potentials for any future use in biomass, crop or gardening needs: "basic information on the samples, known as passport data, is available for only half of the seeds in storage." Vellvé, 1992, 87).

Another major problem with genebanks is the degree to which they actually store diversity. How much variation is held within genebank collections? Differences arise from the fact that you have to conserve not only many species, the importance of which in natural or agro-ecosystems you do not know, but also as wide a variability inside species as possible for cultivated varieties.

For example land races, while being well-adapted to local environmental and climatic conditions, as well as wild forms usually offer excellent and unique sources of resistance to pests. Still world-wide wild species only account for less than 2 per cent of genebank accessions. And of the breeders' lines a large number are duplications, in the case of Europe's barley or pea collections 60 to 70 %. So genebanks can be of little worth in preserving agricultural diversity.

Reserves

How to preserve diversity then? The problems related to the genebanks have already been described. Another solution is the reserve approach.

In agro-ecological systems, like the ones found in tropical forests, that coevolved with the indigenous peoples' values, beliefs about nature, and technological, cultural and social systems (Norgaard, 1988, 207), the interplay between plants and wild varieties and weeds is essential. Obviously taking out large areas from temperate style agricultural production to protect this interplay *in situ* is cost-prohibitive. And what if one is not sure about how large an area one has to protect to ensure the total interplay?

There is definitively an inbreeding problem in smaller refugiums, where it is worsened as inbreeds are less resistant to environmental stress (Frankel and Soulé, 1981, 67). For example in inbreeding maize fitness characters showed the most drastic decline. This means that when the size of a reserve is too small, or the quality of a seed bank too low, the gene pool will eventually drop to dangerously low levels that inbreeding can not be avoided with the dangers that this poses to the quality of the gene pool and the individuals' fitness and so the species survival in that area.

What is known is that the size of islands and their geological history determines the number of species. A destruction of 90 per cent of the land will imply a loss of about 50 per cent of the species[8] (Swanson, 1994, 155), but: "the new equilibrium will not be reached at once. Some species will hang on for a while in dangerously reduced populations" (Wilson, 1988, 12).

The question of the adequate size of a reservoir can also be answered by looking at the life times of various species. The minimal numbers necessary and the lifetimes are in inverse proportion. Shorter lifetimes necessitate protection of a larger number of individuals to prevent genetic erosion and inbreeding. However, shorter lifetimes normally also are accompanied with smaller individuals so that the absolute size of the reservoirs will not grow indefinitely. A more thorough discussion of these problems is given in Frankel and Soulé (1981).

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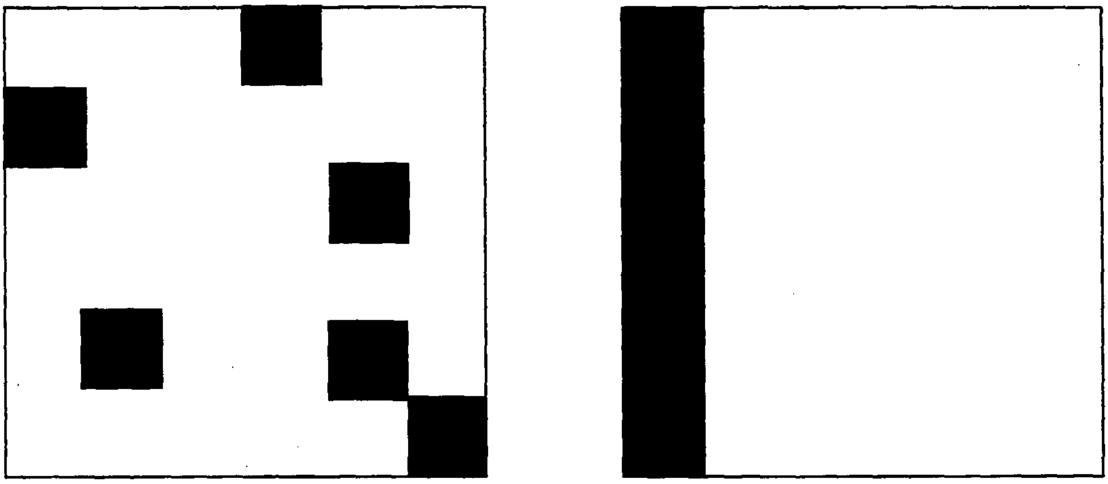
[8] This is is log-linear relationship, also called Arrhenius equation.

A definite answer on the adequate reserve size is still difficult to attain, especially if we also take into account the problem of how to find out, whether a species actually is a keystone species. One could mistakenly feel to have ensured the existence of a species, even though this is not the case for the very long range: "What biogeographers have been discussing is whether roughly 50% of the higher vertebrate species will be extinct in 500 years versus their extinction in 5000 years" (Frankel and Soulé, 1981, 125).

Figure 2 Lack of edge effects in extinctions of dominant species.



Budiansky-Tilman *et al.*, 1996 have shown that the edge effects, *i.e.* the extinction of specific so-called dominant species is independent of the actual distribution of the patches of the original environment (indicated as black squares in the figures) that are being destroyed. So a more organised destruction of only a single belt as shown in the right example, will not reduce edge effects.

Results of dynamical modelling indicate that extinction can occur, even though we can not make out any obvious immediate trends (Kareiva and Wennergren, 1995). It is also worthwhile to note that the species area relationship[9] seems to be independent of the actual spatial pattern of habitat destruction (Budiansky-Tilman *et al.*, 1996), see Figure 2. This is especially flawed for so-called "dominant competitors" that despite this name lack colonisation abilities which r-strategists, the so-called "opportunistic" species on the other hand own. What this in fact means is that for a dominant competitor it does not change its extinction fate whether its habitat is only reduced at the edges or in any pattern more inside its habitat!

Between and Within Habitat

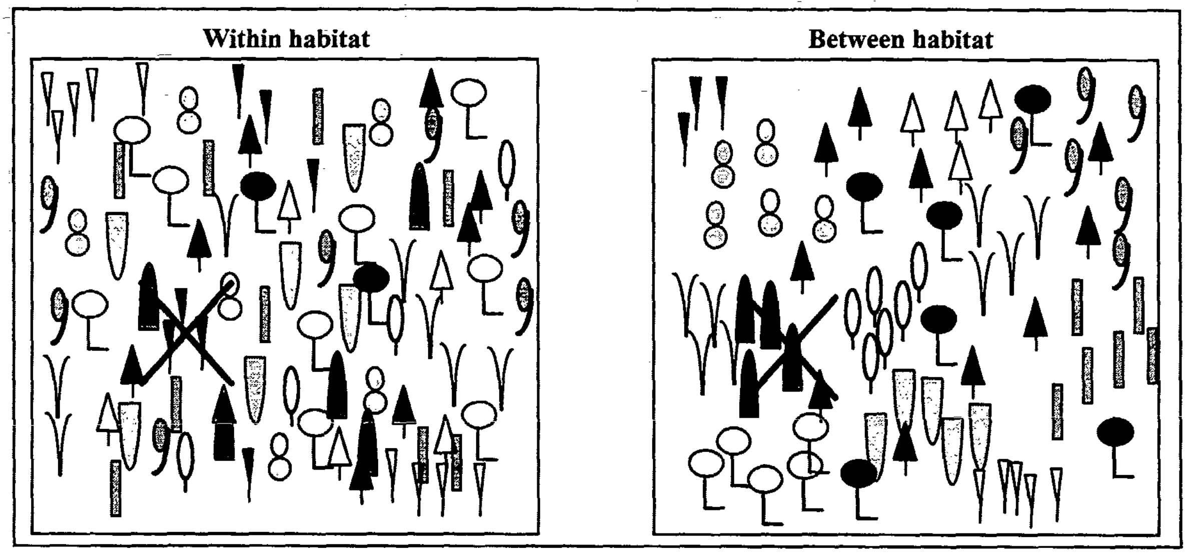
It is quite clear that diversity is declining within species (intra-species) as across species (inter-species) (Swanson, 1995b, 49). But we have to describe yet another assumption, the one of *within*-habitat and *between*-habitat. In the first case some species might coexist in one region so that species A also lives *within* the habitat of species B, in the second segregated

[9] that normally signifies a 50 per cent species loss for a 90 per cent habitat reduction.

islands of groups of species can be found (Roughgarden, 1995, 152) so that species C lives *between* the habitats of species A and B.

In the case of between habitat, the habitat of each species is more sharply defined. Therefore destroying part of the total ecosystem, as indicated by the thick cross in Figure 3, will more likely lead to complete extinction of a certain species than in the within-habitat case. This is just a simplified example, generally some species will occur within-habitat, like large dominant forest trees giving tropical rain forests their structure.

Figure 3 Difference between within-habitat and between-habitat



The difference between within-habitat and between-habitat is that in the first case the different species occur mixed so that each species' habitat lies within that of another species. Exceptions can occur, like riparian species that will only occur at certain locations.

Chances of making one species extinct are much higher when this species only occurs *between*-habitat, so that when the habitat of that species is destroyed so also is the species. The famous diversity richness of the tropical zone is very much a result of between-habitat diversity where species occupy smaller habitats as a consequence of the uniform physical conditions that favour specialisation. Different species occur in separate regions opposite to the temperate zones where species occur more intermingled.

So in the tropics: "entire species are eliminated because they happened to be restricted to the portion of the forest that was cut over" (Wilson, 1988, 11) — a result of tropical species being generally between habitat. On the other hand over middle latitudes the amount of species that are between-habitat and only can be found in small areas might be comparatively smaller as a consequence of larger changes in the physical conditions. So it would be wise to use an assumption of the form that maybe only half the species can be expected to become extinguished from simple habitat destruction in the non-tropical regions.

Domesticated Species

While the protection of wild genetic variety already poses major problems, the actual protection of commercially used domesticated species is not as problematic. First they are already existing abundantly in the genebanks. Then they have had a history of selection and inbreeding, so that inbreeding depression concomitant with further inbreeding is relatively less severe, *i.e.* the furtherance of depression will no longer show drastic results (Frankel and Soulé, 1994, 68).

The danger with domesticated species is that we are concentrating on a very small number of species in human agrosystems today. Land races disappear and legislation does not acknowledge the value of noncommercial varieties (Doll, 1996). On the opposite legislation in Europe prevents diversity by relying on a few large seed companies as advisers in the legislation process.

Currently patent or similar regulation like plant breeders' rights have the tendency to protect just a few genes or simple genetic constructs for *e.g.* herbicide or pest tolerance, longer shelf life, fancy colours, etc. As biotechnology is not so advanced, these qualities will be encoded in only one gene so that pests and diseases will easily succeed to outrun plant breeders' advances, thus rendering traditional farming ever more vulnerable (Vellvé, 1992, 63 ff.).

With the trend to concentrate on yield and the firm believe that diseases can be compensated by chemical treatment the modern crops are problem prone in the future. This development has gone so far that French baking industry has to import wheat from Germany as the French varieties only have high yield but lack decent baking qualities (Vellvé, 1992, 46 ff.).

One problem in the future will also be that some information might be lost as we cannot protect it properly: "At the current state of biogenetical engineering we cannot create new seeds without the old ones. And we do not know what we will want or need tomorrow. Each variety of turnip, squash, wheat or olive that disappears means the irreplaceable loss of part of our past and part of our future" (Vellvé, 1992, 15).

Cultural Diversity Loss, too

When we accept that biodiversity of plants is being reduced by the destruction of natural ecosystems, then we also need to accept that the diversity of human cultures is being reduced. Not only will Rondônia be changed from a thick tropical forest to a bare agricultural region, also the indigenous people, the tribes that have lived there for many generations, and their cultures, will very likely become extinguished. This itself means loss of valuable information for a potential application of the currently still existing, although acutely threatened, biodiversity in that region.

In order to collect new varieties of species it is necessary to know where to find them. When ecosystem people become ecological refugees (Gadgil, 1995, 108) then ethnobotanical knowledge, too, starts to erode rapidly as the people move from their centres of origin to new habitats (Sheldon and Balick, 1995, 52).

The increasing global environmental stresses therefore also impact information dispersal and perpetuation. This means that the loss of cultural diversity brings with it the loss of cultural information like which plants that have medicinal effects for certain illnesses, or whether the plants can be of nutritional value, too.

Another reason for being worried with the ongoing and in the future enhanced loss of cultural diversity is that indigenous communities have consciously fostered genetic diversity within species (Sheldon and Balick, 1995, 57). They also tend to exist in remnant parcels of land areas with high species diversity, so that their expulsion in many cases will be connected to loss of plant genetic diversity anyway.

Apart from the immediate loss of cultural diversity and the chances to find new medicinal plants or maybe new crops, there is also the psychological side of the story. Man's psyche "is genetically programmed to respond positively to nature and its patterns. By destroying so much of the natural environment, we humans are now destroying crucial parts of our own psychological as well as physical habitat." (Iltis, 1988, 99)

Perspectives of Biodiversity Loss

All the previous sections have described the ongoing loss of biodiversity of natural systems, human cultural systems and of plants of potentially global use to mankind. But why is this not only a problem for the tropical region, why will it also be a problem for temperate regions and western-style agriculture?

The success of temperate style agriculture is highly dependent on the inflow of genetic information. For example the origins of Swedish wheat seed stretch as far as South Europe and central and south-western Asia (SOU 1995:88, 66). In these regions wild varieties of wheat can be found that might contain qualities searched for in the future. It might be for reasons of introducing resistance to drought or insensitivity to other environmental stresses or diseases. Wild varieties provide a gene pool in that respect.

Mankind is dependent on biodiversity. The loss in species and varieties occurring today will very likely accelerate in the near future[10] due to increasing environmental and climate stress. This loss shall be described and if possible monetised. It will have direct consequences for agroindustrial systems.

In that respect it is also important to look at the development of the yields in the last decades. Srivastava *et al.* (1996, 5) describe that about half of the breeding success with respect to yield increase depended on genetic improvements. The remaining increase is due to agronomic practices such as mechanisation, irrigation or fertilisation. This sheds an important light on the importance that genetic variety, both within domesticated varieties and wild populations, has for further yield improvements, too.

Apart from existing species new crops for a variety of purposes could be found in indigenous agriculture. Loss of genetical information on pest resistance means that some pests on plants will occur against which no direct defence can be found. Then otherwise high yielding crops have to be given up.

Genetic erosion will become more pronounced during the next decades. First, genetic monotony is already fostered by the centralised distribution of seed material as the financial stakes of introducing new varieties have increased, and seed production has to serve various interests not immediately related to agricultural interests.

One example is the creation of larger agroindustrial conglomerates where functions such as research in fungicides, herbicides and pesticides and the demand for mineral fertilisers are integral parts of new seed design. Such conglomerates are often created to create vertical integration to increase market shares and influence.

[10] the next 10 to 25 years or so.

Causes of Tropical Deforestation

It seems as if the destruction of the tropical forests continues on a wide scale (Anonymous, 1996). Just for the record we cite a table given by Myers (1995, 113) according to which the main cause of tropical deforestation is slash-and-burn agriculture by economical and ecological refugees (Gadgil, 1995, 108) in certain Third World regions.

Table 1 Tropical deforestation: main causes, 1989

Deforestation activity	expanse of deforested land: (km^2)	per cent
Slash-and-burn agriculture	77000	54
Plantations for tea, rubber, oil palm, etc.	8000	6
Cattle ranching (confined to Central America and Amazonia)	15000	11
Destructive logging (SE Asia)	30000	21
Dams, mining, road building	12000	8
Total	142000	100

Original source: Myers (1989).

Opposite to the general, often repeated, statement in the public that it is the logging and mineral prospecting activities, that are responsible for most of the damages, the opposite is actually the case with regard the area impacted. This, however, is of no great help to us, we still only can choose an average value for the economic biodiversity values as elaborated below, as we cannot distinguish the fragility of the regions where minerals like coal, etc., are being exploited, often with disastrous consequences for the native people like the demolition of the sacred sites (McKinney and Schoch, 1996).

Monetising Biodiversity Loss

Introduction of Basic Monetisation Idea

We shall try to establish the costs of species extinction to humanity from an ansatz that has been described in the literature, and we try to extend it to other areas, where species loss has economical consequences, too.

It is quite clear that chances of making one species extinct are much higher when this species only occurs between-habitat, see Figure 3. This might be a valuable approach for most tropical areas where diversity seems to be generally high but also where species seem to occupy only smaller habitats as a consequence of the uniform physical conditions that favour specialisation.

On the other hand over middle latitudes the amount of species that are between-habitat and only to be found in small areas might be comparatively smaller as a consequence of larger variability in the physical conditions. So it would be wise to use an assumption of the form that maybe only half the species can be expected to become extinguished from habitat destruction.

Another important factor to take into consideration has to be the potential loss of varieties of one plant from the success of large scale, western-style agriculture in other parts of the World.

This might be a surprise, but also crops are being grown globally now. For example the largest wheat producer today actually is — China (von Baratta, 1995).

And therefore we should extend the investigation of biodiversity richness by an analysis of the intra-species variety from indigenous varieties. It should be remembered that many varieties are presently being lost. In India today a very small number of rice varieties is grown, a result of the green revolution, Some decades ago, there were several thousands of rice varieties that evolved with the indigenous agriculture in the region and led to adaptation to the regional demands and physical conditions, like soil, climate and work force differences.

Tropical Medicinal Biodiversity Value

These thoughts then lead to the following assumptions. For the question of valuing biodiversity for medicinal purposes Pearce and Moran (1994) or Pearce and Puroshothaman (1995) have assumed between-habitat diversity. They base their figures on estimates on the number of plants that are threatened from extinction, other factors to be described later and figures on the value of plant-based drugs, where different approaches are explained. The data for an investigation on the pharmaceutical market of the OECD countries is given in Table 2.

Table 2 Value of plant-based drugs

	Total value (billion 1990-Euro)	Species value (billion 1990-Euro)
Market value of trade in medicinal plants	19.4	0.485
Market or fixed value of plant-based drugs on prescription	36.5	0.913
Market value of prescription and over-the-counter plant-based drugs	56.7	1.418
Value of plant-based drugs based on avoided deaths, non-cancers	468.0	11.7

Based on Pearce and Puroshothaman (1995, 135). They assume that today the plant-based drugs rely on 40 different species. Values refer to their OECD data. The values in US-$ have been recalculated by using consumer price index (1981=0.6955, 1985=0.8233) and exchange rate values (1990: $1.2373=1Euro_{1990}$) to gain Euro values applicable in 1990. The value of life has been set at 2.6 million $Euro_{1990}$ (EC 1995/2, 508).

The investigation of Pearce and Puroshothaman (1995) thus indicates that a species could have a value of between 485 million and 11.7 billion Euro from pharmaceutical considerations alone.

Besides Medicines

We might want to transfer the ansatz of the pharmaceutical value of tropical biodiversity to other areas like agriculture, forestry, horticulture, gardening, biocontrol agents[11], raw material and biomass production. We stick to considering only plants. The value of biodiversity for these areas and the present use and conservation of diverse systems in indigenous agro-

[11] Those are biological methods to control plant pathogens or pests. They normally are animals, and as such not considered in the following investigation. Some 500 insect species have been deployed worldwide to control crop pests, with good effects. Although they are not as potent as insecticides, they show longer lasting effects, apparently without any damage to the environment (Srivastava *et al.*, 1996, 7).

economic systems have been described by *e.g.* Shiva (1993), so there can be no doubt that we have to take this varied use into consideration.

For this purpose we need an estimate of the global value of agriculture. We start with a rule of thumb value of 2 per cent of the industrialised countries GNP and an information on the global GNP (Baratta, 1995, 954): 24.3 $T\$_{1993}$. This gives a global agricultural GNP of about 500 $GEuro_{1990}$. When we gain more knowledge of the potential value of other species we might find a finer differentiation with respect to the various applications of those species.

Now a new, economically competitive, species should be able to gain a global market share of between 0.1 and 1 per cent of the global agricultural GNP with a mean of 0.5 per cent. This would give an interval 0.5 - 2.5 - 5 billion Euro per year. This compares well with the figure of the US-American agricultural export of about 31.8 billion Euro ($45 bn in 1994; Baratta, 1995, 976) which is only a part of the global agricultural market.

We also have to stress the enormous economic value of biomass. Even if we assume that more efficient use of energy in the future will reduce the amount of primary energy necessary, and that biomass only will gain a market share of about 10 per cent of the present total energy market, then this value will be rather high. The U.S. fuel imports alone have currently a value of 60 billion Euro (McKinney and Schoch, 1996, 341). The loss of a species valuable for biomass production would therefore imply enormous economical losses.

Following Pearce and Puroshothaman (1995) we apply a ratio of 3:1 to upscale the US value to an OECD level, which gives 180 billion Euro. If we assume that a biomass delivering plant species might catch a market share of between 1 and 10 per cent with a mean of 5 per cent then this would give a species value of 9 billion Euro, between 1.8 and 18 billion Euro from the interval assumed.

Table 3 Figures and intervals of species values (in billion $Euro_{1990}$)

	central value	lower value	upper value
Pharmaceutical applications	1.418	0.485	11.7
General agricultural applications	2.5	0.5	5.0
Biomass applications	9.0	1.8	18.0

To conclude, Table 3 gives the overview of how much one species might be worth with respect to various applications of natural biodiversity. We have only assessed the possible revenues generated in the OECD, so the real values could be slightly higher than the ones given in our table. But we presume that our approach will lead to an underestimate under all circumstances, as we might have overlooked some possible uses of biodiversity, and also our restriction to plants only clearly will be at the low end of the total results.

The figures will be used to assess an area-based figure in the next section.

Area Value of Diversity Loss

With the values given above we will try to calculate the biodiversity value of an area that is destroyed as a result of either deforestation, which is applicable over the tropics mostly, or as a result of destruction of natural ecosystems or the conversion of indigenous agricultural systems to modern wester-style agricultural systems.

Basic Idea

We start by presenting the ideas of Pearce and Puroshothaman (1995, 134 ff.). Their formula $V_{mp}(L) = \{N_R.p.r.a.V_i/n\}/H$ gives the value of diversity per hectare for the pharmaceutical biodiversity value of plants of the tropical rain forests, with:

N_R=60,000,	the *number* of tropical plant species to be extinguished in the next decades,
p=1/10000 to 1/1000,	the *probability* of a species to show chemical activity,
r=0.05,	a *royalty rent factor*,
a=0.1 to 1,	the *harvest factor* of honouring intellectual property rights,
V_i/n= 0.39 to 7 billion US$[12]	the *pharmaceutical value* of each substance,
H=1 bn hectares,	the *tropical forest area* left in the World.

The *number* of tropical plant species is about 600,000 (Farnsworth, 1988, 92), of them they have assumed 60,000 to be in danger of extinction in the tropical forest area during the next decades.

The *harvest factor*, a, indicates that in 10 per cent to all cases there would be paid royalties to receivers in the source regions of the genetical information. This is related to the way property rights are treated, and whether the countries in the origin of the biodiversity information can enforce a proper payment. In many developing countries the potential value of biodiversity has already been noticed and fiercer actions to harvest royalties can be expected in the future (Posey, 1996; Shiva, 1995, Beringer, 1996). Thus, the upper value of 1 might be applicable in all cases that we consider.

The *royalty rent factor*, r, measures how much of the drug's value that would be transferred to the collector of the materials. This is equivalent to a licence fee paid to the owner of a patent, that might be a share of the total revenue generated by a product. For reasons given just before for the harvest factor in the future the royalty rent factor could be more than 0.05.

V_i/n has before been given as an extension of the work of Pearce and Puroshothaman (1995) , see Table 3, and we shall use these new values.

Results for Tropical Pharmaceutical Value

The original data given in Pearce and Puroshothaman (1995) indicate a pharmaceutical biodiversity value of from 0.01 to 21 US$ per hectare, or on a 100 year basis and at 3 per cent discounting, about 660 Euro/ha. Pearce and Puroshothaman (1995, 137) defend their upper value

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12 the original values used by Pearce and Puroshothaman (1995, 134 ff.).

by comparing it to an example of harvesting medicinal plants in Belize. They stress that in the light of ignorance actual values must be much higher when loss of very large tracts of tropical forest places also other species, probably with key status, at risk.

The medicinal value of biodiversity is impressive. But it might be overexposed, as we will see in the following discussion when we extend our investigation with an analysis of other possible applications for tropical, but also temperate, biodiversity, where we will assume the same values as given above, except for the number of species at risk and the area over which to calculate.

New Agricultural Applications

Using a range of values between 0.5 and 50 billion Euro per species for general agricultural applications with a central value of 5 billion Euro will, using the same values as before for *p, r, a and H,* give a present value[13] of one hectare of 470 Euro within the range from 0.47 to 4700 Euro.

We have to caution that this value for agricultural biodiversity of tropical forest area is only a rough estimation. The upper value of the success ratio of 0.001 for finding a useful plant might still be far too small. Remind you that of the 250,000 flowering plants known today already 80,000 have edible parts, which would argue for a success value of about 0.3! It therefore seems to be necessary to use another interval for agricultural and biomass applications. A range of 0.001 to 0.01 with a central value of 0.005 seems to be applicable for those purposes.

Outside the Tropics

To transfer the ansatz of Pearce and co-workers to other areas and regions of the Earth we need to pinpoint some facts of importance. We should reduce the number of impacted species not only as generally there are fewer species outside the tropics but also because they will be mostly within-habitat, so that only 50 % are in immediate danger from area changes.

There is a diversity gradient from the non-tropical to the tropical regions, and the species density per hectare is typically only 10 to 50 % in middle latitudes compared to the tropical belt (Mooney, 1988, 159). We use an optimistic 50 %. By using this approach, we also qualify for those situations over the middle latitudes where rare species actually have been become nearly extinct, and so in fact have become between-habitat. Although they might have been wide spread before, as in the example of the plant corn cockle, *Agrostemma githago*, mentioned above, they now occur only in small patches, probably in reserves, and so might face extinction easily.

Thus, the following values will be used now for non-tropical evaluation:

N_R=15000, the *number* of non-tropical plant species likely to be extinguished,

r=0.07, a *royalty rent factor*,

a=1, the *harvest factor* of honouring intellectual property rights,

H=3 bn hectares, non-tropical *area* in the World.

[13] @ 3 % and 100 ys.

For pharmaceutical applications we assume the same success rates as for tropical biodiversity values, *i.e.* a mean of 0.0005 with a span of 0.0001 to 0.001. For general agricultural and biomass applications we assume a success rate of 0.005 with a span of 0.001 to 0.01.

We are using a *royalty rent factor* because of the increasing public awareness of the economic value of diversity, which argues for a higher compensation for biodiversity in the industrialised countries, and a high value of *harvest factor* for the same reasons.

The 3 billion hectares are a simple result of looking at the area of different non-tropical and non-desert areas, where values on the areas of climate zones (Hupfer, 1991, 226f, table 5.2) have been used.

The *probability* to find a useful plant will be taken as in the tropical example.

Results

Before we present the results for the three kinds of biodiversity applications we aggregate the figures that we have reached until now.

Table 4 Data aggregate of biodiversity applications

Range of values:	central		lower	upper
V_i/n for applications (billion Euro)				
Pharmaceutical	1.418		0.485	11.7
General Agricultural	2.5		0.5	5
Biomass	9		1.8	18
p for applications				
Pharmaceutical	0.0005		0.0001	0.001
General Agricultural	0.005		0.001	0.01
Biomass	0.005		0.001	0.01
Type of region:	**tropical**	**temperate**		
N_R	60000	15000		
r	0.05	0.07		
H (billion hectare)	1	3		

For the three possible applications of natural biodiversity we reach the following values, presented in Table 5:

Table 5 Area based biodiversity values

$V_{mp}(L)$ for applications (Euro per hectare)	Tropical	Non-Tropical	Tropical		Non-Tropical	
Range of Values:	central		*lower*	*upper*	*lower*	*upper*
Pharmaceutical	**2.1**	**0.2**	0.15	35.10	0.02	4.10
General Agricultural	**37.5**	**4.4**	1.50	150.00	0.18	17.50
Biomass	**135.0**	**15.8**	5.40	540.00	0.63	63.00

Thus, the values[14] of possible tropical medicinal applications have been extended to the typical area loss[15] over the other non-desert regions of the World. We have to stress that these values are still only a first approach to monetising the species and variety loss in the other areas than the tropics and the field of pharmaceutical uses, and that they only take into account the loss of species from pure land-use changes, *i.e.* deforestation[16]!

Variety Values

Now our approach so far has only considered finding new species for various purposes. This section therefore is on the value of a variety of a crop plant. This means the variability within one species as a result of local adaptation. Even though wheat as a species does not get extinguished when one of its indigenous varieties disappears somewhere in the World, exactly this variety might be the only one able to cope with a new upcoming wheat pest!

In fact modern agriculture is uttermost dependent on a steady influx of genetical information from wild relatives or indigenous varieties to the established crop plants. This has been the major reason for the ongoing improvements with respect to yield or resistance to pests (Srivastava, 1996, 5). This is the reason for including a special investigation of varieties of crop plants and their potential diversity values.

Examples

When we speak of varieties, we are a little bit in a grey zone between indigenous agriculture and land races by slightly advanced agricultural systems and wild relatives to existing crops. The examples given below might illustrate the range of sources and applications.

Vogel (1994, 19) cites the example of the wild species of maize, *Zea diploperennis*, a perennial plant, which because of this quality alone was estimated to have a value of Euro 6.5 billion ($\$6.82$ billion_{1985}). Even more it is highly viral resistant, too, which would pose for still higher values. It is not clear whether this value is gained from a present value approach (see in the section below), where any future income from those qualities have been discounted to a present value. We assume that this is the case.

Iltis (1988, 102) tells that a wild tomato, *Lycopersicon chimielwskii*, that he and co-workers had discovered, had shown to increase the soluble-solid content of commercial tomatoes by about 2 percentage points, which would be equivalent to market value of Euro 7.5 million per year ($\$8$ million_{1987}).

Present Value of Variety Biodiversity

In the example above, the figure given by Iltis (1988) is a yearly value of the tomato business. In order to give a better estimate of the total value, we should try to estimate how much such a yearly value is worth with respect to a long-term investment.

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[14] The figures given in Table 5 only give yearly averages not the total present value! See the following sections.

[15] These values could be used when establishing the potential biodiversity losses from area use changes like a new mineral mine in a virgin rain forest or a natural preserve in non-tropical areas.

[16] On the major reasons for deforestation today see Table 1.

If we for example say that the Euro 7.5 million are applicable over the timespan of a hundred years[16] then we have to correct any future income by a rent factor that describes our preference for having some amount of money today rather than in several years from now. This rent is chosen to be 3 per cent per year, a value applicable to long term investments. With these assumptions the *Present Value* of the tomato variety becomes Euro 237 million.

When we also assume that the value given in Vogel (1994) is corrected for long term capital streams then we have at least a span of 237 million to 6.5 billion Euro as an economical value for a variety. Now these values are difficult to translate to area averages as in the other cases of biodiversity value that we have presented so far. Here the area might be anything from some hectares, for the case of a land race grown by some indigenous farmer, to several thousand hectares for a region that might harbour a wild variety like in the maize example. An upper value of 1 million hectare (= 10,000 km^2) is chosen here. This is probably a rather high value, but we could imagine that some agriculture is being performed very extensively, *i.e.* on a large area, so that any research would have to cover that area anyway.

If we argue for the same probabilities, harvest factors and use the high royalty rents factor for non-tropical diversity[17], then the variety diversity could range as described in Table 6.

Table 6 Crop variety biodiversity value (Present value assumptions)

Range of values:	**central**	**lower**	**upper**
r	0.07		
H (hectare)		1.0E6	10
V_i/n		(billion Euro)	
General Agricultural	2.5	0.237	6.5
Biomass	9	1.8	18
p for applications	0.005	0.001	0.01
Land present value		(Euro per hectare)	
General Agricultural	292	0.02	455000
Biomass	1050	0.13	1260000

Note: the lower and upper value of the area are exchanged as the low value in the upper column ensures the high value of the biodiversity factor.

So it can be seen that the area value of crop varieties can be really very high, up to over a million Euro with the assumptions that we have made in our calculation.

The reader might ask why we have not assumed any medicinal use of varieties. The answer is that varieties of crop plants generally not seem to have much pharmaceutical use, and that one would still stay within one species so that new compounds with pharmaceutical applications might not seem easy to find, so that we need not take this feature into consideration.

[16] One could argue that for such long time spans the value should not be calculated but only for a shorter one, as varieties generally tend to have short economic livespans. This is generally the case if one looks at the immunity against crop pathogens, where new pests necessitate the introduction of new resistant strains. However, the quality of the tomatoe is a feature that is being valued over a longer period.

[17] This is plausible, as we are talking about farmers who, being educated somewhat better and having access to existing economic and social structures, will have better chances to gain higher rents than most indigenous peoples.

Conclusions

We have shown that biodiversity occurs in a series of areas, that give rise to an economical value. This value is presently not being considered when decisions are made to change an area's land use pattern, be it the conversion of virgin forest or other kind of natural land to agricultural land or the abolition of traditional agricultural practices, with their tending of indigenous varieties, in favour of a highly mechanised and chemisized western-style agriculture.

It seems that the economical value of biodiversity needs to be treated more diligently in the future, differently from today's approaches, where it is not considered to pose any economic factor. The values given in Table 7 show that the values could be rather important to take into account, when we change the pattern of the Earth.

Table 7 Aggregate values and ranges of biodiversity for different applications per hectare

Range of values:	central	lower	upper
PV for applications	**Tropical Regions**		
Pharmaceutical	**67**	5	1109
General Agricultural	**1185**	47	4740
Biomass	**4266**	171	17063
PV for applications	**Non-Tropical Regions**		
Pharmaceutical	**8**	1	129
General Agricultural	**138**	6	553
Biomass	**498**	20	1991
PV for applications	**Crop Plant Varieties**		
General Agricultural	**292**	0.02	455000
Biomass	**1050**	0.13	1260000

Values given in present value $Euro_{1990}$ per hectare with 100 year time scale and 3 % for tropical and non-tropical areas. Different approach as explained before for crop varieties.

It can generally be stated that the pharmaceutical value is not the highest value that biodiversity offers. Despite the often stated importance of new medicines stemming from newly discovered plants[19] we can see that this application actually does not seem to be the most important one from an economical point of view. But it certainly is the most prestigious to treat and present to the public.

Caveat

We have to stress that the figures given here are not the final result on that matter. Biodiversity and natural ecosystems perform a bunch of services to mankind, like extracting CO_2 from the air and providing oxygen and products from the primary production. These recycling

[19] Once again the taxonomic discrimination has to be countered by investigating whether other sources of substances with pharmacological qualities can be discovered from *e.g.* fish, coral reefs or insects. This is an area that needs more research, but the approaches shown here can be applied in that fields, too.

processes, and the cleaning of exhaust from industrial sources, are probably much higher in total worth, even though they from an area average might seem smaller.

It is noteworthy that our average assumptions of course can not be applied to the small number of *megadiversity* countries; Mexico, Colombia, Brazil, Zaire, Madagascar and Indonesia; who count for a large magnitude of the richness in diversity (Mittermaier, 1988, 152).

Climate Change Outlook

We have heretofore only considered the importance of area changes for biodiversity loss. It might be necessary to extend the ansatz presented here to elaborate on the consequences of global change brought about by changes in the radiative forcing of the surface-atmosphere climate system. The scope of this impact is global, and so would seem to have vast consequences. This is another subject in need of a similar investigation. That it is important has been shown by Peters (1988) and Schwägerl (1995) who described, how climate change leads to adaptation, or in the worst case extinction, of species and ecosystems.

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