Encyclopedia of Life Support Systems.
EOLSS Publishers, Oxford. 2002.

BIODIVERSITY: THE IMPACT OF BIOTECHNOLOGY

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Keywords: Biodiversity, biotechnology, native biodiversity, agricultural biodiversity, convention on biological diversity, Cartagena protocol on biosafety, conservation, crops, agriculture, ethics, transgene, genetics.

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1. Introduction

The Convention on Biological Diversity requires that all Member States take measures to preserve both native and agricultural biodiversity. The intrinsic value of species and ecosystems, in addition to their value as starting material for finding new products, is the basis for these measures.

The biggest threat to biodiversity is habitat destruction. The ever-increasing spread of cities and the accompanying expansion of agriculture must be held largely responsible. Humid tropical forests are particularly valuable reservoirs of biodiversity and are currently being seriously threatened. As the human population expands, the need for food is expected to double in the next 30 years, with the ensuing threat of massive habitat destruction particularly in the less developed countries. Increasing crop productivity on the land already under cultivation would prevent or at least reduce habitat destruction. One of several measures aimed at increasing yields is the use of better seeds, including those enhanced by modern biotechnology. Many other measures from the technical, socio-economic and political fields need to be taken at the same time in order to balance intensification and sustainability of modern agriculture.

Modern biotechnology offers new means of improving rather than threatening biodiversity. If properly tested for both risks and benefits to humans and the environment, transgenic crops are more likely to increase agricultural biodiversity and help maintain native biodiversity rather than to endanger it. Such applications need to be judged by the criteria of improved sustainability and compared to current as well as alternative farming practices.

2. The Essence of Biodiversity

Biodiversity is the multitude of different living beings in a particular ecosystem or on the whole earth. Biodiversity can be seen and studied at different organizational levels: genetic, organismal and ecological. It touches upon both native environments on land and sea as well as agricultural and other man-made surroundings.

2.1. Native Biodiversity

The biodiversity we observe today is the result of 3.5 billion years of evolution. Through the processes of mutation and selection all living organisms we know today, as well as those that ever lived before, developed from one single-cell micro-organism. How this first living being arose 3.5 billion years ago is still a matter for speculation. This unitary origin explains why all organisms share the same basic chemistry: DNA is always the storage molecule of genetic information and the complex process of protein biosynthesis is virtually the same in all organisms. Metabolic pathways are also similar in all organisms (see also *Cell metabolism*), e.g., the reactions by which energy is generated or the way in which fatty acids, sugars and amino acids are made. Separate species arose when mutations between relatives no longer allowed for interbreeding, for instance after geographic or reproductive separation.

Dinosaurs are by no means the only creatures of the past that became extinct: far more organisms lived at some time on our earth than are living here today. The vast majority, probably more than 99 percent, of species that arose on this globe, disappeared again. This shows that evolution is an ongoing process, with species coming and going. This dynamic situation is important when discussing the conservation of species living here today. In the long-term view, there has never been any stability in life on earth - only change. However, these changes were very slow compared to the length of a human life, or even compared to the time humans have existed. Clearly, today, with the massive amount of human interference on the globe, changes are much faster than at any other time in the last 65 million years, the point at which the trilobites and later the dinosaurs and many other creatures vanished from the surface of the globe in a relatively short time period.

As suggested by Raven in 1992, the number of species of plants, animals and eukaryotic micro-organisms is probably around 10 million today, but only 1.4 million have been characterized and given a name by scientists. There is much variation in what is known about the different groups. Virtually all of the 40 000 vertebrate animals are known and most of the 300 000 vascular plant species as well. On the other hand, there are likely to be over a million species each of fungi and nematodes, of which only 70 000 and 13 000 have been named. There are thought to be far more than a million different insect species as well. With prokaryotes, the situation is even more extreme: about 5 000 bacteria and viruses have been named individually, yet the total number in both of these two groups may well according to Bull be in excess of one million. Since many micro-organisms and viruses are associated with specific plants and animals, Staley considers their own biodiversity will depend on the biodiversity of their hosts, as well as the micro-organisms' own host range.

All the different species of plants and animals do not live an independent existence, but are associated in specific communities and ecosystems to form more or less stable associations. One such association is, for instance, the humid (and dry) tropical forest, which is generally thought to have the highest degree of biodiversity, with more tree species per km^2 than there are tree species in North America or in Europe, as discussed by Burslem. Another example comes from specific types of alpine meadows or specific sorts of rivers or ponds. Biodiversity needs to be considered not only in qualitative terms of the species present, but also in quantitative terms, considering how many individuals of certain species of plants and animals are present. With large mammals this is quite easy to determine, but it is impossible with micro-organisms. Often the number of species found in a given ecosystem is taken as a measure of the biodiversity of that system: other criteria are more difficult to apply.

In this paper, we will concentrate on terrestrial biodiversity, although it is clear that streams, lakes and oceans provide habitats for a vast biodiversity of animals, plants and micro-organisms. In addition, as calculated by Naylor in 2000, they are an important source of protein as food for humans and feed for farm animals, with about 120 millions tons used per year.

2.2. Agricultural Biodiversity

In addition to biodiversity in the wild, there is the biodiversity of organisms used for farming and other human activities. In agriculture, 7 000 species of plants are used by farmers somewhere in the world, but only 30 species provide 90 percent of our calorific intake. intake as observed by Haywood in 2000 Within these dominant crop species, there are many hundred thousands of varieties (landraces, cultivars) adapted to local climates, farming practices, and cultural predilections like taste, color, structure, ability to store the products etc. Much of this large crop diversity is important for providing the initial material for breeding. However, it must be recalled that the genetic diversity found in crops is much less broad than the genetic diversity observed in plants or animals living in the wild, which points to the importance of wild species for agricultural breeding programs. The top three crops are wheat, rice and maize (corn) with around 500 million tons annual production each. Traditional breeding (see also *BG6.58.4.12*) led us in to the trap of narrowing down genomes, and perhaps wisely used biotechnology could bring back at least that part of genetic diversity which enhances pest resistance and also yield (see also *BG6.58.4.3*).

There are many indications that mixtures of varieties of a crop or of different crops may give higher yields and be more resistant to pests and diseases than monocultures, as reported recently by Zhu for rice in China. However, even in mixed cultures, high quality, well defined varieties and pure seeds are required and the sustainability of mixed cropping related to pest management has still to be proven. In addition, it is still not clear, whether or not, in natural, non-agricultural habitats yield is dependent on biodiversity. Based on experimental results, some researchers claim that the loss of species leads to a reduction in biomass, while others disagree, as demonstrated by Hector in 1999 and by Kaiser in 2000. There simply may not be valid correlations between biodiversity and biomass yield, in either agricultural nor non-agricultural settings.

2.3. Human Population Expansion

The one species that is still globally expanding in numbers are humans. The world population has gone up from 2.5 billion in 1950 to 6 billion today; it is expected, by the UN, to reach 8 billion in 2015 and 9 - 10 billion in 2050. Over 95 percent of the expected population increase will be in the developing countries. In those countries, most of the population growth will occur in the cities. The additional population will require more space to live in, more water, more energy, more food and more services. For the years 1995 - 2020 the largest relative population increase (80 percent) is expected in sub-Saharan Africa: in absolute numbers it is expected to go from 500 to 900 million. It is not clear whether the HIV/AIDS epidemic, with an estimated 25 million infected in this region in 2000, will substantially affect population dynamics within the next 25 years, as most of the infected are of reproductive age, as pointed out by Cohen in 2000. It is important to realize that the FAO estimates that there are over 800 million people globally who don't have enough to eat today, and it is imperative that more food be produced for them where it is needed, namely in the developing countries. As pointed out by Lipton in 1999, pPoverty reduction in rural, agricultural areas of developing countries is also likely to have an indirect effect in favor of the urban poor. Improved seeds will have a positive effect, but many other factors such as education, access to microcredit, reduction in farm subsidies in the North etc. will be at least as important.

3. International Agreements

In view of the importance of biodiversity for the future of mankind, several international agreements have been reached. Since this has occurred only in the last few years, the long term impact of these agreements cannot yet be estimated.

3.1. The Convention on Biological Diversity (CBD)

Recognizing that the biodiversity of organisms in the wild should be maintained both for their own intrinsic value, but also on practical grounds, the United Nations prepared the Convention on Biological Diversity (CBD) and succeeded in having it adopted in 1992. It entered into force in 1993. This is the first time that a large majority of States , have agreed to a legally binding instrument for biodiversity conservation and the sustainable use of biological resources. A radical change brought about by the CBD is the recognition that States have a sovereign right over biodiversity within their own territory: previously organisms were considered to be the common heritage of mankind. Living organisms or their products may, under the terms of the CBD, only be removed from a country under mutually agreed conditions. The CBD is a comprehensive approach to biodiversity conservation of both wild and domesticated species. It aims at conservation at the genetic, species and ecosystem levels. As reviewed by Buhenne-Guilmin, action is delegated to the national level obliging States to assess biodiversity, enact legislation for its conservation *in situ* and *ex situ*, and to enforce legislation within national boundaries.

The field of biotechnology is particularly affected by articles 16 and 19 of the CBD, since they require a fair and equitable sharing of benefits derived from the use of genetic resources. This includes providing facilities and financial means for technology transfer and open access to scientific and technical information. The sovereignty over biological resources means that noone can remove specimens of plants, animals or micro-organisms from a country without the prior consent of that country. One example of a joint effort in "bioprospecting" is a search for specific active ingredients of plants by the Merck Company in the tropical forests of Costa Rica. This brought the country 2 million dollars over a five year period, in addition to the potential for royalties, should profitable products emerge. A small number of similar agreements have been undertaken elsewhere in the world.

The regulations of the CBD have only been in operation for a few years. It is too early to assess their long-term effects. As far as biotechnology and "bioprospecting" is concerned, it will take more time to establish smooth administrative procedures to allow simple routine implementation of close collaborations. This system will only be perpetuated if both the national authorities from countries rich in biodiversity, and pharmaceutical or other companies see the mutual advantages to be gained from such collaboration. One of the real obstacles to this are the exorbitantly high costs of drug testing that needs to be done to meet strict and justified regulation before marketing. The expectations of some LDCs to make rapid earnings may have been too optimistic. The search for natural, highly active pharmaceuticals in wild plants may often be more cumbersome than laboratory searches using genomics, rational drug design and combinatorial chemistry.

3.2. The Cartagena Protocol on Biosafety

The CBD provided a basis for developing and formulating a further international agreement, namely one primarily regulating the trans-boundary movement of living GMOs. After much debate in 1999, the new protocol was agreed upon in early 2000 under the name of the "Cartagena Protocol on Biosafety". The "Intergovernmental Committee for the Cartagena Protocol on Biosafety" had its first meeting in Montpellier in December 2000. It paved the way for launching a pilot phase of the "Biosafety Clearing House", a centre for information exchange, as explained on the internet.

The Protocol is a worldwide regulation for the transfer, handling and use of GMOs that may have an adverse effect on biodiversity, also taking into account risks to human health and focusing on transboundary movements. It makes explicit reference to the precautionary approach. It establishes an Advance Informed Agreement (AIA) procedure for imports of GMOs intended for introduction into the environment and an alternative procedure for mass movements of GMOs intended for food, feed and for processing (commodities). The permit for transboundary movement will or will not be issued on the basis of a risk assessment procedure performed by the national competent authority. The Protocol does not pertain to pharmaceuticals or other non-living products made by genetic modification.

In practice, the Protocol will be most important for the import of transgenic seeds. It requires a risk assessment by the national authorities and allows countries to reject GMOs. The protocol specifies that "lack of scientific certainty due to insufficient scientific information and knowledge regarding the extent of the potential adverse effects… shall not prevent the party from taking a decision" This may or may not be in agreement with the WTO rules, but will need to be tested in the courts. If there are disputes between the interpretation of the Protocol and the WTO regulations, which allow for trade barriers virtually only if there are scientific reasons to do so, the outcome of such disputes will depend to a considerable degree on the quality of scientific data used for assessing the benefits and risks of GMOs.

The Protocol is likely to become operational in the year 2002, after ratification by 50 nations. Early in 2001 it had been signed by 86 nations and ratified by two. The Protocol will, as pointed out by Mahoney, be a challenge to the scientific community to provide solid scientific data to convince national authorities of the benefits of transgenic crops and their relatively low and manageable risks. It is far too early to make any assessment of the Protocol's effect. Hopefully it will allow (and not prevent) the planting of GM crops that may have real advantages for developing countries, while at the same time minimizing their risks to humans and their environment. The Protocol may contribute to a better public understanding of what transgenic crops are, but it may on the other hand, by treating GMO crops as a special group, increase fears of a negative impact, even in the absence of any science-based data showing such an impact. It will be difficult to move forward with the Precautionary Approach, if it is taken as a stringent principle. It will be more advisable to see the Precautionary Approach as guiding a case by case decision-making tree, in the sense of a systems approach as described by Verma Niraj of the Churchman School from Berkeley, California.

4. Loss of biodiversity and Conservation

Losses of biodiversity are undoubtedly occurring in many parts of the globe, often at a rapid pace. These losses require countermeasures such as an increased effort towards conservation by many different means.

4.1. Reduction of Biodiversity

The loss of biodiversity can be measured by a loss of individual species, groups of species or decreases in numbers of individual organisms. In a given location the loss will often reflect a degradation or a destruction of a whole ecosystem. Recently the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) of the CBD ranked the priority of threats to global biodiversity in the following manner: first comes habitat loss (most of it through the expansion of cultivated land), second comes the introduction of exotic species. Habitat loss comes not only from taking more land under the plough, but also from expanding cities and road building. In addition, habitats can be damaged by flooding, lack of water, climate changes, salination etc., all of which phenomena that may be both natural or man-made.

Since tropical humid forests are particularly rich in biodiversity, their destruction is disproportionately damaging to biodiversity. It is estimated by Pimm and Raven that of the original 16 million km^2 of these forests known a century ago, only half are left, with about one million km^2 being destroyed every 5 to 10 years. Burning and selective logging may damage an even greater area. Biodiversity is not homogeneously distributed over the humid tropical forests, rather there are hotspots with a particularly high level of biodiversity. These hotspots are of particular interest for the implementation of conservation measures.

The second most important reason for loss of biodiversity is invasion by exotic plants and animals. Knowingly, or unknowingly, imported plant species threaten the native ones by being highly competitive and often by lacking local predators, such as insects or birds. One of the most extreme examples is seen in the pampas of Argentina, a flat grassland with a moderate climate, from which nearly all the native grasses have disappeared and have been replaced by European plants. This invasion was brought about by European farmers who introduced animals and crops, in addition to accidentally spreading many different weeds. This phenomenon was already noted in 1833 by Charles Darwin. Today, still, droves of gardeners transport seeds all over the globe and never think of the possible threat to biodiversity, as suggested by Ammann in 1997. It has been estimated that one in ten imported plants may spread in a modest way and that one in a hundred may turn into a nuisance weed. Even in today's Europe, invasion by exotics may threaten ecosystems. In the Ticino region of Southern Switzerland *Robinia pseudoacacia*, a native of North America, is displacing chestnut and oak trees, whilst in the Northern regions of the country *Solidago canadensis* is replacing native irises in swampy areas. Islands are particularly threatened by invaders, as is well documented for Hawaii, New Zealand and the Galapagos Islands. For North America, it has been estimated that the damage caused by exotics amounts to137 billion dollars a year. Although such calculations are fraught with uncertainties, there is no doubt that the costs of exotics are tremendous.

Exotic biological control agents are often introduced to agricultural ecosystems on purpose, in order to control pests or weeds without resorting to chemical control agents. Whilst there are some success stories, Strong pointed out in 2000 that such systems may also go wrong. One example is the introduction of the seven-spot ladybird, which was intended to fight the Russian wheat aphid. The consequence, however, was the disappearance of the native ladybirds, for which the seven-spot import was a competitor and an actual predator. Another example is the decimation of the large American moths, which are killed by European *Compsilura* flies, introduced nearly a century ago to control the gypsy moth. Field experiments recently done by Jensen showed that caterpillars of the American moth *Cecropia* were killed by massive infestations of *Compsilura* maggots.

It cannot be said today, on the basis of experimental evidence, whether transgenic plants are specifically prone to spreading in the long term. However, one would not expect this to be the case unless the transgenic plant had an increased fitness. There is no good argument why crops that have for centuries depended for survival on human care should become weeds, just because of the addition of one or a few well characterized genes, in addition to the many thousands of genes they already carry. However, this issue needs to be carefully studied on a case by case basis, keeping in mind that the absence of a negative effect can never be proven with absolute certainty. The results of a fairly long-term study of the performance of transgenic crops in natural habitats were recently presented by Crawley in 2001. Four different crops (oilseed rape, potato, maize and sugar beet) were grown in 12 different habitats and monitored over a period of 10 years. In no case were transgenic plants found to be more invasive or more persistent than their conventional counterparts, in agreement with the general hypothesis put forward above.

4.2. Conservation Strategies

Conservation may be *in situ* or *ex situ*, either in the natural or semi-natural habitat, or in some purpose-built environment. The choice of one or the other technique, or a combination of both, will depend on the particular case. *In situ* conservation will involve the maintenance and protection of natural habitats, while botanical gardens and seed banks are used for the *ex situ* conservation. Both of the latter require precise knowledge of taxonomy.

Conserving a substantial, but selected fraction, of the humid tropical forests would still allow half or so of their indigenous species to be preserved. This would require a selection of the most appropriate areas, called the hot spots. Protecting huge tracts of land will pose major socio-economic and political problems. It has been asked how forests destined to be protected from human encroachment can be kept free of hungry people in search of potential farmland (Mace in 2000). Jennings thinks that a viable strategy may be to find a sustainable livelihood for rural populations in connection with conserving tropical humid forests. Policing alone will not be successful over vast territories, as seen today in the war on drugs in South America and Asia.

Today, conservation also embraces various components of agro-biodiversity like crop varieties, land races, semi-domesticates and crop relatives. The role of indigenous communities in maintaining agro-biodiversity is stressed by the Global Biodiversity Assessment and the Leipzig Plan of Action, two recently concluded international agreements.

5. Applications of Biotechnology and its Effect on Biodiversity

The methods of biotechnology can be applied to the study of virtually any biological phenomenon and will in some cases have practical applications for maintaining biodiversity. Conversely, threats to biodiversity by biotechnology also need to be considered.

5.1. Biotechnology for the Acquisition of Knowledge

In the context of this paper there are two quite different applications of biotechnology, or of molecular biology, that are relevant. The first is the use of biotechnology as a tool for acquiring knowledge, whilst the second is the use of biotechnology to directly intervene in plant and animal breeding, in particular to transfer genetic information from one sort of organism to a particular crop, or to a farm animal to make it transgenic (see also *Transgenic plants*, and *Transgenic animals*).

Today, biological research can hardly be conducted without using biotechnology in one way or another. Taxonomy uses molecular markers to identify individual strains of organisms or to identify species, much in the same way as in forensic medicine to identify criminals. This is useful for *ex situ* conservation of plants and micro-organisms. In seedbanks, (see also - *Culture Collections and Genebanks*), genetic fingerprints are used to establish the origin of a seed or the relatedness of one plant variety to another. A rational classification of most micro-organisms has only become possible with these biotechnological methods. This is important to the many collections of micro-organisms that exist around the world.

Biotechnology has also proven useful for following genetic markers in plant and animal breeding. Here, animal or plant varieties are crossed by conventional, sexual means. By analyzing a few cells of the newly born calf or of the newly sprouted crop, one can predict some of the expected properties of the progeny, by looking at the presence or absence of certain forms of genes. This enables one to predict a phenotypic property, which will only show up later in life, for instance certain characteristics of a cow's milk or the crop's expected resistance to an infectious plant disease. Using *in vitro* fertilization of animals, the laboratory test can be done even before the embryo is implanted. This is called pre-implantation diagnostics.

These applications of biotechnology are in general not controversial. Here, the public perception is similar to the application of modern biotechnology in medicine, for instance to industrially produced pharmaceuticals, vaccines and diagnostics. It may be noted that the worldwide sales of biotechnology products in 1999 was worth around 13 billion dollars in the medical field and only 1.6 billion in agriculture.

The availability of genome sequences will be a boost to research. The first two complete plant genome sequences determined were those of *Arabidopsis* and rice. The 120 million base pairs (MBP) of the small brassica *Arabidopsis* were sequenced by an international academic consortium and the data made public. The 430 MBP sequence of rice was completed only a few weeks later by an industrial group lead by Syngenta, and will be available by contract to other researchers. Syngenta intends to make the data available free of charge for research directly benefiting subsistence farmers. The public sector sequencing of rice through an international consortium is expected to be completed in 2004. It will hopefully become common practice for companies to make their basic discoveries publicly available, to everyone's benefit. The Monsanto company has also opened up some of its rice sequencing data.

5.2. Direct Gene Transfer to Crops and Farm Animals

Since all genes consist of DNA, and the information in this DNA molecule is read in the same way in all organisms in order to make proteins, it is in principle possible to take any (single) gene from any organism and transfer it into any other organism so that the recipient produces a protein normally only made in the donor. The resulting organism is called transgenic (see also *Methods in Genetic Engineering*). From the time this simple strategy was devised, it took molecular biologists about twenty years until the first transgenic plants were made in 1985 (see also *Transgenic plants*). Ten years later, the first transgenic crop appeared in supermarkets in the USA, the "FlavrSavr" tomato. In 2000 there were, worldwide, about 45 million hectares planted with commercial transgenic crops.

Most transgenic crops planted commercially in 2000 were in the US, Canada, Argentina, with smaller amounts in China, Australia, South Africa, México and Spain. Soyabean and corn ranked first and second, making up 57 percent and 22 percent of the total area planted with GMOs. Cotton and canola accounted for about 5.3 and 2.8 million ha each, whilst only small areas of transgenic potato, squash and papaya were grown commercially. With regards to the genetically-modified traits, herbicide tolerance was dominant with 74 percent, while insect resistance was 19 percent. According to the ISAAA, the amount of virus resistant crops was quite small. Compared to 1999 there was an increase of 10 percent in the area planted with GMOs. For corn there was a decrease, presumably because of an anti-GMO-wave that started in Europe in early 1999; soya and cotton showed an increase.

The reason that US farmers have adopted the transgenic crops surprisingly quickly is because of the economic benefits they offer. In most surveys done by different researchers in different parts of the US, the yields were the same or somewhat higher with the new seeds (www.internutrition.ch). The most noticeable difference to the farmers was the saving on herbicides. The US National Center for Food and Agricultural Policy cited an annual saving of US$ 220 million to soyabean farmers. It was also found that the new crops needed less frequent sprayings and allowed "no till" management. These benefits mostly offset the initial higher cost of the transgenic seeds, although farm profits, with or without modern biotechnology, vary a great deal from year to year and region to region. Clearly these economic considerations only hold for countries with economic structures similar to those of the US, not to developing countries.

It is important to remember that a large number of transgenic crops are still in the development stage and will only come onto the market in a few years from now. They are likely to show benefits for the consumers and some may be of particular interest to farmers in tropical countries. Two rice varieties, with anticipated consumer benefits, are those containing Vitamin A or an increased level of iron in the product, which were developed by Potrykus and Beyer last year. Despite traditional preventative measures (distribution of free vitamin A, encouragement to eat more fruit and vegetables), worldwide there are 130 million young people who are vitamin A-deficient, one to two million die annually as a consequence of vitamin A-deficiency and 500 000 turn irreversibly blind every year. A bowl of 300 g of this cooked rice is thought to be enough to overcome the vitamin A-deficiency to a significant degree. Similarly iron-deficiency, particularly prevalent in pregnant women, can potentially be alleviated by rice containing an increased amount of iron in its endosperm. Such rice varieties have been successfully developed in the laboratory, but are far from commercialization, for both scientific and political reasons.

For farmers in developing countries, the following GMOs may be of interest:

- virus-resistant cassava
- virus-resistant sweet potatoes

- virus-resistant papaya (already on the market in Hawaii)
- rice with an increased rate of photosynthesis, and therefore with a potential yield increase of up to 25 percent
- rice with increased salt tolerance
- diverse varieties that are partially aluminium-resistant and have the potential to grow in degraded tropical soils
- diverse crops that are more drought-resistant than the usual varieties.

All of these and many more crops have been proven to work, in principle, in laboratory and glasshouse trials. The practical benefits and risks of the crops need to be assayed in the field and their products scrutinized, like any other novel food. Several lines of transgenic farm animals have been produced, but none have been made commercial. Some lines are made for the pharmaceutical industry to produce drugs in their milk. Others may show improved resistance towards certain infections. Transgenic salmon that grow faster than normal have been developed and have roused considerable concern amongst ecologists. As pointed out by Reichhardt, many environmental issues still need to be clarified in this context. However, it is clear that the transgenic crops that have been commercialized so far have not been seen to have done any harm to either the environment or consumers.

5.3. Native Biodiversity and Biotechnology

Biodiversity in the wild has been massively reduced in the industrialized countries over a long period of time, in Europe, for example, over several millennia. Hardly any ecosystem is the same here as it was before humans started to clear forests and develop farming. When we look out of the window we see houses, roads and meadows, whilst three thousand years ago the area was covered in beech and oak forests. Even Europe's forests are more like manicured gardens than virgin forests, despite the mystical "naturalness" attributed to our forests, at least in Germanic countries. North America still has far more native, untouched ecosystems, either in the form of protected areas or in less hospitable regions like the North of Canada. Biodiversity has already diminished on a massive scale in the industrialized countries.

Despite many conservation efforts, about half of the tropical humid forests have already been destroyed. How then can the rest be preserved, given that the regional population is increasing rapidly, as for instance in sub-Saharan Africa, where a near doubling of the population is expected in the next 25 years? Already today, the per capita food supply in sub-Saharan countries is only 2100 kilocalories compared to 3500 kilocalories in the industrialized countries, so there will be a huge pressure to provide more food. Even if some food is imported, the vast majority has to be produced regionally or nationally, both for reasons of economy and ecology (e.g., poverty reduction, transport and distribution costs).

Yields of cereals have gone up very considerably in the last forty years. In the developing countries, this is primarily a result of the Green Revolution. However, the annual growth increases in cereal yields have slowed down from about 3 percent to 1 percent per year as shown by Pinstrup-Andersen and his collaborators in 2000. For the developing countries they were 2.8 percent in 1967-1982, 1.9 percent in 1982 - 1994 and only 1.2 percent in 1993 - 2020. These lower yield increases of recent years mean that productivity will probably not keep up with demand in the developing countries. The consequence on biodiversity is devastating and means that more land will be required for farming. This land will primarily come from areas with high native biodiversity, in particular the aforementioned tropical humid and dry forests or from marginal land. Whilst the green revolution has also had negative consequences, such as salination, excessive water use and soil degradation, the increased productivity it achieved allowed the maintenance of large tracts of native untouched land not used for farming.

Conway concludes that the single most promising way to avoid habitat destruction is to increase farm yields in a process that has been called the second green revolution. Several components will be required to increase productivity: better training and education of farmers (in particular women), more favorable economic and political climate, availability of microcredits etc. In addition, technical contributions will also be necessary. One such contribution is improved seed, produced either by traditional crop breeding or by modern biotechnology. There will have to be more reliance on the latter, since traditional breeding seems to have reached a yield plateau. So agricultural biotechnology, which is viewed controversially in the public debate, may contribute markedly to conserve biodiversity by preventing the appropriation of native biodiversity-rich land for farming purposes. It should be noted, however, that this technology - like all others - is no panacea. Pinstup-Andersen and Cohen believe that each application needs to be studied carefully on a case-by-case basis, like any other new technology.

A valid concern is the possible effect of Bt-crops and similar plants on non-target insects. The Bt-crops contain a gene coding for an insecticidal protein originally produced by the soil bacterium *Bacillus thuringensis* (see also *Production of Biopesticides*). They were developed to make the plants resistant to a particular, highly damaging pest and have been quite successful in reducing pesticide input when infestation rates are high. In laboratory studies Losey showed in 1999 that the pollen from Bt-corn could kill larvae of the Monarch butterfly when a large amount of pollen was sprayed on the larvae's favorite food plant, milkweed. Subsequent field studies by Sears showed that the Bt-corn caused little or no damage to the Monarch in real agricultural settings. This shows that the impact of transgenic crops on non-target organisms cannot be studied solely in the laboratory, but also requires farmland experimentation.

A more limited concern, that largely touches Northern Europe, is the conservation of native plants and animals, in particular birds, in farmed areas. The birds' habitats are fields, hedges, roadsides and fallow land where they depend for food on insects and seeds produced by weeds in or near the crops. These seeds are particularly important in the winter months. Computer models by Watkinson suggest that more intense weed control measures may lead to smaller amounts of seeds being available to birds. This effect seems plausible under certain conditions, but depends on weed management regimes rather than on the presence or absence of transgenic plants, and therefore is not an issue of biotechnology. Herbicide tolerant beets may allow farmers to tolerate weeds for a longer time and fight them only after sowing. This is made possible by a post-emergence herbicide treatment. More efficient weed management may also make it possible to set aside more land. If the lack of food results in a reduction in the bird population, this may lead to an increased number of harmful insects in the fields. It must be remembered that farming the land serves quite different purposes, particularly in Northern Europe. The primary goal is obviously the production of food, but secondary goals, such as conservation of biodiversity and giving city dwellers opportunities for outdoor activities, are also important. For the latter purpose, setting aside more farmland would be helpful. In order to do this, political will and financial incentives are a prerequisite.

5.4. Agricultural Biodiversity and Biotechnology

In addition to wild plants, old landraces might be threatened by transgenic crops. It should be remembered that vertical gene transfer by pollen has always occurred between different old landraces and between different new varieties of crops. Despite this, varieties of apples or cereals have been stable over many years and specific traits have not disappeared. Pollen has always flown.

What has become far more precise is the method of analysis. Thanks to gene probes and to GMOs, it has become much easier to follow gene flow, since one is no longer dependent on visible traits, but can follow a specific gene. Nevertheless, it is important to preserve landraces and native relatives of crops for their intrinsic value as well as for having starting material for future crop breeding.

Can newly introduced transgenic crops transfer genes vertically to native wild plants and thereby change important characteristics of the wild plants? Vertical gene transfer between cultivars and wild plants has always occurred within the limits of species, if the two types of plants were in close proximity and flowered at the same time. No new problems can be expected from transgenic plants, except if the gene transferred from the GMO to the wild plant significantly increased the fitness of the recipient. This seems rather unlikely *a priori*, but needs to be studied experimentally, as suggested by Ammann and collaborators in 1999, both in the laboratory and the field. Herbicide resistance transfer from a herbicide tolerant, transgenic crop to a close relative can occur in the field, as has been shown for canola by Mikkelsen in Denmark. However, this would be of major significance only if the recipient weed was controlled by this herbicide in this farm setting.

Small farmers in many developing countries use a remarkable number of races of many different crops. These are often well adapted to the local climate and topography, and are used to produce foods for different cultural purposes. In the Andes region of South America, dozens of different varieties of potatoes are grown, often side-by-side on small plots. In Europe, different varieties of potatoes are used for the industrial production of chips, and for preparing rösti in the home. Will the traditional races disappear when, and if, transgenic crops are introduced by farmers in developing countries? To judge from the past in Europe, the answer will be largely yes, not because of any biological hazard emanating from the GMOs, but because farmers need to produce their products and sell them economically. Many old varieties of apples have disappeared in Europe because of the preferences of the food retailers and consumers, who buy just a few varieties. The rapid consolidation in the global seed market is also a concern for the maintenance of agricultural biodiversity: a decreasing number of companies control the global seed and agrochemical markets. Anti-trust legislation needs to prevent the formation of overly powerful monopolies. This concern is not a consequence of the introduction of agricultural biotechnology, but a consequence of globalization. New technologies have, not only in biotechnology, but also in many other areas, made large companies more powerful and more visible. It may be possible that modern breeding methods based on molecular genetics will *per se* reverse the trend of variety losses, since the insight in genomics may bring back respect for races and the need to conserve them.

6. Social Consequences

The introduction and spread of new technologies generally have social consequences with winners and losers. For biotechnology, this has led to intense public debate across many different facets, among them ethical, economic, legal and emotional (see also *Biotechnology in the Environment: Potential Effects on Biodiversity*, and *Why Genetic Engineering Causes Concern - Social, Cultural and Political Impacts*).

6.1. Economic Considerations

One may wonder under what economic conditions biotechnology will benefit agricultural productivity, prevent the expansion of farmland and thereby help the preservation of biodiversity. It is worth remembering that the green revolution, which improved wheat and rice production in Asia, was initiated through work done in the public sector, namely in the Philippines at the International

Rice Research Institute (IRRI) and in México at the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), both institutions which belong to the Consultative Group of International Agricultural Research (CGIAR). Today, innovative research in agricultural biotechnology is largely done by a few large companies, with smaller contributions from the public sector. That companies strive for intellectual property rights (IPR) through patenting or other protective mechanisms is understandable and largely unavoidable, if innovation is to be maintained. However, provisions need to be made so that the agricultural research institutions of developing countries can obtain easy access to the patented materials and procedures as well as to the knowledge they need in order to improve the position of poorer farmers, as proposed for instance by IRRI.

A very limited number of transfers of specific patents have already occurred, such as from Monsanto to the Kenyan Agricultural Research Institute for producing virus-resistant sweet potatoes or another to IRRI for the promoter genes used in golden rice. This approach, including the possibility of forced licensing, is more practicable than wanting to overthrow the world's patenting system with the slogan "No patents on life". The patenting system does, however, need to be adapted in order to do justice to the complexity of living organisms. It may be noted in passing that the first patent granted for a living organism was given to Louis Pasteur in 1873 for a specific type of yeast.

A new issue arising in the field of IPR is the attempt to protect traditional, indigenous knowledge and preserve biodiversity through new international legislation (see details in Girsberger reference). This legal instrument is still in an embryonic state of development.

At the level of the individual human being, the lack of food appears to be, and is, largely a problem of distribution: there is not sufficient food available where it is needed. In addition, the poor simply do not have the money to buy sufficient food. Since in developing countries most of the poor still live on the land, it is there that more income has to be generated, so that there is not only enough for survival, but a surplus which can be sold on the market. Increasing agricultural productivity is the most effective way to do this and should, according to economists, embrace modern biotechnology as an important component.

6.2. Ethical Considerations

The issues involved in the interaction between biodiversity and biotechnology have far-reaching consequences and need to be subject to an open and knowledge-based dialogue in society. The heated public debate, seen primarily in Europe in the last couple of years, and which in some circles led to near hysteria, is according to Leisinger not sufficient to solve the underlying problems. The dialogue needs to include many different stakeholders, including farmers of developing countries, diverse scientists, policy makers and communicators. Cultural values involved in farming and food production need to be taken into consideration, just as much as the emotional side of eating and drinking *(*see also *Inventions, Patents and Morality).*

A significant aspect of ethical behavior is openness. Transparent information is required both from scientists in non-commercial settings as well as from industry. Although competition from fellow researchers and from industries does not allow the immediate divulgence of all research results, both groups should make concessions to the interested public and to policy makers. This should be done by scientists personally and would help improve mutual confidence.

Several large projects in biotechnology like HUGO, the Human Genome Organization, have an "ELSI" component, dealing with ethical, legal and societal implications of biotechnology. This shows that some scientists realize that science cannot be seen as a human activity taking place in a void, without any connection to social and political realities. Ethicists stress that it is the responsibility of scientists to be actively concerned with these issues and that they should take special responsibility in communicating with non-specialists to explain what they know as well as what they don't know. Matrices of criteria have been set up for instance by Mepham to make it possible to ask relevant questions, such as who and what may be affected by agricultural biotechnology, and what properties like well-being, autonomy or justice may or may not be infringed upon. The questions put forward by ethicists need to answered on the basis of concrete scientific knowledge, using comparisons with other, established agricultural practices. Ethicists will have critical and thought provoking questions. However, their answers and attitudes may vary considerably. If they are positive as Comstock, ethicists will suggest pursuing research and application with appropriate caution. There is no easy answer to what the word "appropriate" means, beyond answering questions on a case-by-case basis to balance the benefits and risks. Actively shaping the future and attempting to solve problems always involves risk.

It will be important to see ethics not as a stable set of principles, but rather as a discursive process, which will be able to cope with the growing speed of new developments. The Nuffield Council of Bioethics recently came to the conclusion that "The moral imperative for making GM crops readily and economically available … is compelling", if well-informed governments of developing countries want to introduce them. This imperative should be taken seriously and treated with urgency: every day 20 000 children die of malnutrition and 30 000 ha of humid tropical forest are destroyed.

Acknowledgements

I thank Dorothy Braun for many hours of painstaking editing.

Glossary

Biodiversity: The multitude of different living beings in a particular ecosystem or on the whole earth

Biotechnology: Use of cells (plant, animal, microbial) and their components to produce useful substances and other products

Genetic Modification (GM): introduction of isolated genes or pieces of DNA into another organism. Synonymous terms are gene technology, and genetic engineering

GMO: genetically modified organism. A synonymous term is transgenic organism

GT-Food: food produced from GMOs

Modern Biotechnology: biotechnology including the use of genetic modification of the producer cells and other newer procedures

Transgenic: genetically modified

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