Exploring Biotechnology For Conserving Himalayan Biodiversity

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Abstract: The Himalaya is one of the largest and youngest mountain ranges of the world, and covers 10 percent of India's land area. Extending across much of the northern and northeastern borders of the country, the Himalayan massif regulates climate for a broad portion of Asia and provides ecosystem services (especially perennial water systems) to much of the heavily populated plains of India. In addition, due to its unique location as the meeting place of three biogeographic realms, species diversity and endemism in the region is unique. At the same time the region is extremely fragile as a complex result of tectonic activities and anthropogenic influences. On account of its unique and diverse ecosystems and high levels of threat, the Himalaya has been recently designated as a global biodiversity hotspot by Conservation International. [Researcher. 2009;1(3):36-45]. (ISSN: 1553-9865).

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"*Biodiversity is the very core of our existence within our communities. You cannot say how many dollars this is worth because it is our culture and our survival. In this context biodiversity is invaluable … We value our surroundings as our identity, as who we are and our inheritance that is given to us … Our environment is many things, a classroom, a pharmacy, and a supermarket*."

Ruth Lilongula, Solomon Islands (UNEP/IT, 1999, p.162)

Himalayan Biodiversity

The Himalaya is one of the largest and youngest mountain ranges of the world, and covers 10 percent of India's land area. Extending across much of the northern and northeastern borders of the country, the Himalayan massif regulates climate for a broad portion of Asia and provides ecosystem services (especially perennial water systems) to much of the heavily populated plains of India. In addition, due to its unique location as the meeting place of three biogeographic realms (the Palaearctic, Indo-Malayan and Mediterranean), species diversity and endemism in the region is unique. At the same time the region is extremely fragile as a complex result of tectonic activities and anthropogenic influences. On account of its unique and diverse ecosystems and high levels of threat, the Himalaya has been recently designated as a global biodiversity hotspot by Conservation International.

In northern India, the Himalaya extends across the states of Jammu and Kashmir, Himachal Pradesh and Uttaranchal. The Himalayan region falling within this zone is classified into two major biogeographic zones: the Trans-Himalaya and the Himalaya. The windward slopes of the Great Himalaya and associated ranges form a large biophysical zone is classified under the Himalaya biogeographic zone **(Rodgers and Panwar 1988)**. Ecosystems in this zone encompass one of the largest altitudinal gradients in the world, range from the subtropical forests of the Siwaliks to alpine meadows and scrub in the higher peaks of Great Himalayas. Some of the richer assemblages of wild and medicinal plants are found in this region. It has been estimated that the region supports over 4500 species of vascular plants **(Western Himalaya Ecoregional BSAP 2002)**. **Champion and Seth (1968)** classification includes 11 major types (and 47 subtypes including several stages and disturbance types) in the Himalaya. The key features of biological diversity in this region include: i) wide latitudinal, altitudinal and moisture gradients encompassing a large number of ecosystem types, ii) high levels of diversity and endemism, iii) unique examples of agro-biodiversity, iv) species of great commercial value, and v) unique indigenous knowledge systems.

Agro-biodiversity recorded from the region is unique and records of medicinal plant species are available which are traditionally being used by the people. The mid-elevation oak (*Quercus spp*.) forests found in the region are ecologically as well as economically important. A number of species such as *sal* (*Shorea robusta*), *chir* pine (*Pinus roxburghii*) and *deodar* (*Cedrus deodara*) has been extracted for their wood. Recently extensive harvesting of medicinal species such as *Taxus wallichiana, Aconitum heterophyllum* and *Picrorrhiza kurrooa* is causing concern. High plant species diversity and productivity of this zone is matched by a diverse assemblage of faunal elements. Avifauna in this region is diverse and over 640 species of birds have been reported of which 205 are endemic **(Western Himalaya Ecoregional BSAP 2002).** Bird species of maximum conservation importance include the pheasants such as the Western Tragopan (*Tragopan melanocephalus*), the satyr tragopan (*Tragopan satyra*) and the Cheer pheasant (*Catreus wallichi*). With respect to mammals, the lower altitudes, especially the Siwalik zone has significant populations of elephant (*Elephas maximus*) and tiger (*Panthera tigris*). The temperate zone has a large number of resident species; among these are endangered species like the musk deer (*Moschus chrysogaster*), the Himalayan *tahr* (*Hemitragus jemlahicus*) and the Kashmir stag or *hangul* (*Cervus elaphus hangulu*). Compared to birds and mammals, reptiles and amphibians are less studied and less diverse, especially in the higher altitudes. Fish species diversity is considerable and a large number of fish species have been introduced into the region. The golden *mahseer* (*Tor*), which is found in the lower and middle altitude streams and rivers, is now endangered. Reliable estimates of invertebrate diversity for the region are not available. Over 450 species of butterflies (*Lepidoptera*), more than (each) of *Hemiptera* and *Isoptera* are reported from the region **(Western Himalaya Ecoregional BSAP 2002).**

The impact of biotechnology on various aspects and economic progress of various nations around the world has given a major impetus to accelerate research, development and application of this field in relevant socio-economic sectors. Himalayan biodiversity is a woderful niche for exploring the potential of microbial, animal and plant world. The cell fusion techniques, recombinant DNA technology, protein engineering and structural biology have made phenomenal progress as priority research areas. In addition to basic research, the scientists are actively engaged in fermentation based activities, production of valuable biologicals, plant or animal cell culture, marker assisted selection and breeding, value addition, prospecting of biological resources, molecular taxonomy and micropropagation methods for producing high quality, genetically superior planting materials.

Present Problem

The primary threats to biodiversity conservation in the Himalaya include deforestation, commercial extraction of medicinal plants, grazing, invasive species, poaching, and growth of orchards, pollution, eutrophication and global warming. Over the last decade, the high rates of biodiversity loss, particularly in developing countries, have come to the forefront as one of the two most urgent global environmental issues. At the same time, the biotechnology industry has grown rapidly, and the two issues have become closely linked.

The Convention on biological diversity started as a document drawn up by IUCN on the *in situ* conservation of biodiversity. The document was submitted to the UNEP Governing Council, which accepted the need for an international biodiversity convention and accepted responsibility for its drafting. The draft convention was broader than the IUCN document and covered conservation, wild species of commercial crops, and the transfer of technology, biotechnology and expertise to developing countries. Formal negotiations, involving different delegates from 75 countries, started in November 1990 and a final version of the convention was signed in 1992 by 156 nations (including Pakistan) at the UN Conference on Environment and Development, the Earth Summit, in Rio de Janeiro. The convention aims to save animal and plant species from extinction and restore their habitats.

The convention stipulates that parties must develop national strategies for the conservation and sustainable use of biological resources; establish protected are as, resuscitate degraded ecosystems, control alien species and establish conservation facilities; establish training and research programmes for the conservation and sustainable use of biodiversity and support such programmes in developing countries; promote public education and awareness regarding conservation and sustainable use of biodiversity; carry out an environment impact assessment prior to any proposed project that may reduce biodiversity; recognize the right of governments to regulate access Dragon fly/Khushal Habibi Cobra/Ayesha Vellani *Calotropis procera*/WWF-Pakistan to their own genetic resources, and wherever possible, grant other parties access to genetic resources for environmentally sound uses; encourage technology and biotechnology transfer, particularly to developing countries; establish an information exchange between the parties on all subjects relevant to biodiversity; promote technical and scientific cooperation between parties, particularly between developing countries, to enable them to implement the convention; ensure that countries that provide genetic resources have access to the benefits arising from them; and, provide financial resources to developing countries in order to enable them to carry out the requirements of the Convention.

OVERVIEW OF BIOTECHNOLOGY AND BIODIVERSITY CONSERVATION

Strengths and Status

The Himalaya a global hotspots of biodiversity, is now receiving importance from researchers as well as policy makers and a number of institutions are involved in biodiversity conservation in the region. A few of these are solely focused on the Himalaya, and the region also benefits from a number of national level state of the art institutions and scientific expertise that is located within the region. Significant strides in biodiversity research have been made by universities and institutes located in the region. Although yet to be implemented at the grass-roots level, sustainable use models, traditional livelihood practices, knowledge and benefit-sharing are finding mention in recent policies and planning documents. These prepare the ground for future initiatives relating to participatory conservation and sustainable use frameworks. Currently, a number of NGO initiated livelihood and sustainable use projects are going on. One of the unique capacities of the region is the heightened environmental consciousness of local communities. This is especially so in the Uttarakhand Himalaya where voluntary movements to protect forests and biodiversity have been initiated by the local people .

Priorities and Strategies

The need of the hour is to conserve biodiversity through physiological and biotechnological advancements. In particular, it is to determine whether the biotechnology industry, through bioprospecting, can generate enough socially sustainable profits to function as an incentive to biodiversity conservation. After an overview of the links between biodiversity conservation and biotechnology and their early history, present goal is to analyze the current institutional framework surrounding this issue, and in particular the conflict between the TRIPs regime and the Convention on Biological Diversity over property rights on genetic resources and traditional knowledge. Additionally, need is to look at whether bioprospecting efforts have achieved enough economic viability – in terms of profits generated for the private sector – and social sustainability – in terms of benefits to local communities be an effective way to promote biodiversity conservation. While the evidence is mixed, there are enough success stories to suggest that under a stable institutional framework, bioprospecting efforts in which local communities are fully involved can be an effective tool in order to help preserve certain biodiversity rich areas.

Along with climate change, biodiversity loss is probably the most pressing environmental issue currently facing the planet. Broadly defined, "*biodiversity encompasses the diversity of life forms present on the planet*". Traditionally, this has meant species diversity, but the definition can be broadened to include genetic diversity. The importance and visibility of biodiversity conservation as a crucial international issue have been greatly increased since the signing of the Convention on Biological Diversity (CBD) in Rio de Janeiro in 1992, and the CBD's definition best broaches the different views of biodiversity: '*biological diversity means the variability among living organisms from all sources, including interalia terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity between species, within species, and of ecosystems'*. The CBD also highlighted the fact that biodiversity protection and economic development issues are inexorably linked. This is due to the fact that the most important areas for biodiversity conservation fall almost entirely within the developing world. A survey of **Mittermeier *et al* 1997** has identified seventeen countries – which have been named "megadiversity" countries, which alone account for over 80% of the planet's biodiversity. The majority of these seventeen countries are in the developing world, particularly in the Andean region (Venezuela, Colombia, Ecuador, Peru), the Amazon basin (the above plus Brazil), and in south Asia (Malaysia, Philippines, Indonesia, India, China), along with several other large countries, most of which are part of the developing world.

While overall levels of biodiversity are obviously an important indicator of conservation importance, there are two other factors which need to be taken into account when identifying priority areas for biodiversity conservation. The first is levels of endemism, meaning the number of species which are found in a particular area and nowhere else in the world. The second is the level of threat faced by an area, as urgent conservation efforts need to be concentrated where the threats are most imminent. Particularly high levels of endemism are to be found in island ecosystems in countries such as Madagascar, Indonesia, Papua New Guinea and the Philipines, but key areas also include the Chocò ecoregion of Colombia and Ecuador, the Tumbesian region in Ecuador and Peru, the Upper Guinea rainforests of West Africa and many others.

Among the most highly threatened ecosystems are the Atlantic coastal forests of Brazil and, again, island ecosystems in countries such as the Philippines. It is easy to see how any discussion of global biodiversity conservation policies must take into account international development issues, and how conflict can easily arise between developed and developing countries when dealing with such issues. There are different types of efforts and strategies currently underway to preserve global biodiversity, and a brief overview, particularly with regards to how they can be linked to biotechnology development, is useful. The most widespread and the most effective way to preserve biodiversity is through, direct, *in situ* conservation that is, establishing protected areas where biodiversity levels are particularly high or threatened, and these are the types of conservation efforts recommended under the CBD.

However, this is not always as straightforward as it sounds, as the creation of protected areas inevitably means that access to natural resources is restricted. In order to better involve local communities in biodiversity conservation efforts, a number of market based conservation strategies have been developed, which aim to make biodiversity conservation profitable. The better studied ways to achieve this has been ecotourism, the attempt to promote sustainable, low impact tourism to protected areas as a a way of generating income for local communities that would then find economic incentives for the conservation of natural ecosystems. Bioprospecting, the exploration of poorly-known ecosystems aimed at finding potentially useful genetic material that can be used in biotechnology falls into such market based biodiversity conservation efforts. Furthermore, biotechnology can play an important role in *ex situ* conservation efforts, as one of the cornerstones of such efforts is the establishment of gene banks which are vital to the success of the biotechnology industry.

Policy and Priorities of indigenous knowledge and benefit-sharing

Inadequacies among policies include blanket adoption of policies on these regions without considering the present culture, customs, practices and traditions. Advocacy is absent and seems to be adopted only as a political tool for delaying actual development. A few advocacy projects in the region are taken up by small NGOs and do not seem to have an impact on a regional scale. Various institutions dealing with utilization of resources need to be brought on a common platform to frame guidelines for sustainable use, IPR and benefit sharing and biotechnology policy.

Linkages need to be made between research institutions and key regulatory agencies for the region as a whole. Currently these linkages are somewhat blurred. Areas that should be addressed as priorities are biotechnology and benefit-sharing. Policies need to emerge from research outputs. Similarly linkages need to be established between various agencies carrying out development activities and regulatory agencies. Environmental impact assessment plans also need to be drafted specially for the Himalaya. An important systemic need for the Himalaya would be a region specific action plan. Inter-institutional linkages need to be improved for specific issues such as climate change. Studies on climate change require multidisciplinary inputs ranging from bio-physical sciences to socio-economic studies. Inter-institutional collaborations can also contribute to sharing scientific infrastructure and expertise, infrastructural development such as field stations and effective interdisciplinary research.

For the Himalayan region in particular specific policies are needed to address equitable benefit sharing, documentation and preservation of traditional knowledge (e.g., health, agro-pastoral, water conservation systems) and intellectual property rights. It is desirable that a separate set of policies be developed for the Himalaya. As a part of such a project, checklists, databases and status reports of species with commercial importance (especially medicinal plants) can be compiled. Policy formulation needs to be comprehensive and should be developed in conjunction with research institutions as well as all concerned higher level governmental departments to avoid contradictory policies. Efforts need to be made to communicate policy guidelines to the relevant customs departments and regulatory bodies.

In the absence of a comprehensive agro- biodiversity policy, the erosion of agro- biodiversity in the hilly regions of Uttaranchal is continuing unabated. Consequently, there is significant ecological degradation and furthermore, food security of poor farmers is threatened. The objectives of the project are: (i) exploration of the variety of agro ecosystem practices, (ii) the development of appropriate policy instruments that will promote the conservation of agro-biodiversity and achieve food security in the region. A central feature of the degradation of multiple ecological functions is a loss of natural and crop biodiversity in this fragile Himalayan ecosystem. The area under traditional crops has been declining and these have been replaced by cash crops. However, the popular notion is that access to roads in the hills reduces agro-biodiversity. The thrust of government policy instruments, like credit, subsidy, and the public distribution system, has been directed towards promoting high productivity monocultures.

India has a rich and varied heritage of biodiversity covering ten biogeographically zones, the trans- Himalayan, the Himalayan, the Indian desert, the semi-arid zone(s), the Western Ghats, the Deccan

Peninsula, the Gangetic Plain, North-East India, and the islands and coasts (**Rodgers; Panwar and Mathur, 2000).** The COP to the Convention on Biological Diversity adopted a supplementary agreement to the Convention known as the Cartagena Protocol on Biosafety on 29 January 2000. The protocol seeks to protect biological diversity from the potential risks posed by living modified organisms (LMOs) resulting from modern biotechnology. It establishes an advanced informed agreement procedure for ensuring that countries are provided with the information necessary to make decisions before agreeing to the import of such organisms into their territory.

Environment and Biodiversity Conservation

In recent years, efforts of conservation are being made in the country. Many international organizations like IUCN, WWF, ICIMOD and KMTNC rendered help in this effort. By establishing national parks, wild life reserves, and botanic gardens measures of *in situ* conservation have been taken to protect plants animals *from* human encroachment. Such activities are very expensive and thus remained limited. Field gene banks are also costs a lot to maintain and moreover plants and animals maintained in such gene banks are susceptible to natural calamities. Diseases, cattle, herds, other animals, human encroachment and natural disasters often damage them. Therefore, conservation of rare and endangered species through multiple means is desirable. Biotechnological methods can be implemented to support *ex situ* and *in situ* conservation. The accessible means of biotechnological method in developing countries can be implemented in conservation of plant species. Application of hormones can promote propagation of rare species through seeds and other vegetative parts. Dissemination of propagated plants in wild is expected to make the measure of conservation a success. It is possible to maintain biodiversity *ex situ* using tissue culture, protoplast fusion, embryo transfer, cryopreservation and gene banks. The approaches of reintroduction of tissue culture raised plants and establishment of gene banks in nature may thus be effective both *in situ* and *ex situ* conservation of plant genetic resources.

To facilitate absorption and utilisation of technology, major emphasis has been given on involvement of user industry and demonstration of technologies developed at the site of the industry. In over a dozen projects, a number of industries are involved in process development, process optimisation and validation. A number of technology packages such as ecorestoration of mine spoil dumps, microbial remediation of petroleum sludge and oil spill, phytoremediation of dye industry effluent treatment and palm oil mill effluent treatment have been standardised and are being negotiated for technology transfer.

Characterization and conservation of endangered species including medicinal and aromatic plants

A number of valuable plants species bearing food, fodder fuel wood, fiber and medicine are being used in huge amount by people. Adequate measures have not been taken yet to multiply and domesticate these plant species in order to conserve them. Genetic diversity of important species of the Himalayan region has been studied using molecular markers for conservation of these identified elite's in the Alpine region, field stations have been established in Himachal Pradesh – Rahala (2250 m) and Uttaranchal, Katochira, Distt. Almora (1850 m) and Khaljum, Dist Bageshwar (2450 m). These field stations are concentrating on the maintenance of germplasm and on farm cultivation of the elite material. Based on the genetic profiling studies, elites of *Aconitum heterophyllum, A. balfourii*, *Podophyllum hexandrum, Valeriana jatamansi, Gentiana kurroo and Picrorhiza kurroa* are now being taken up for mass multiplication at Rahala, H.P. and Almora. Morphological studies of *Podophyllum hexandrum*, *Valeriana jatamansi*, *Picrorhiza kuroa* and *Gentiana kurroo* have been done. The phenomenon of gynodioecism has been established in *Valeriana jatamansi*. In *Gentiana kurroo*, the peculiar mechanism of dichogamy has been established. Flowering in *Picrorhiza kurroa* occurs in two phases in May/June and August. Seed germination studies in *Podophyllum hexandrum*, *Valeriana jatamansi*, *Aconitum heterophyllum* and *Gentiana kurroo* have been done. The best sowing time for *P. hexandrum* and *A. heterophyllum* is November while as that for *V. jatamansi* and *G. Kurroo* is June. Besides, the use of conventional propagation methods, application of *in vitro* propagation techniques offers an additional alternative for recovery as well as multiplication of endangered species. Therefore, attempts were made to develop effective *in vitro* propagation protocols for *P. hexandrum*, *P. kurrooa* and *A. balfourii*.

The Network of the three gene banks set up by the DBT is fully equipped with state-of- the art facilities for conservation of seeds, live plants and *in vitro* material of rare, threatened and economically important species. A fourth gene bank has been established at RRL, Jammu to cover Western Himalayan Region. Under an integrated programme on taxol, about 1500 rooted stem cuttings of *Taxus* were planted in their natural habitats in Himachal Pradesh. The genetic diversity among *Taxus wallichiana* growing in the

North Himalayan region has been estimated by RAPD analysis. This will help tagging high - yielding genotypes using DNA markers for micropropagation and mass multiplication. Various callus lines of *Taxus baccata* were screened by TLC/HPLC for taxol/10-DAB (a taxol precursor) production. Three promising cell lines were identified. The work carried out at NII; New Delhi has led to the identification and isolation of an isoquinoline alkaloid, berberine, an immunomodulatory agent from *Berberis aristata.* An MOU has been signed between NII and an industry for production of a herbal product. Permission from Drug Regulatory Authority is being sought for carrying out clinical trials in collaboration with the industry. A programme on "Biotechnological approaches for herbal product development" has been launched under the National Jai Vigyan Science & Technology Mission. It aims at developing improved ergot production technology, agrotechnologies for high yielding variety of *Artemisia annua* and developing herbal therapeutic products for curing hyperlipidemia and arthritis alongwith other immunomodulators.

Biological diversity in Himalayan region is closely linked to the livelihood and economic development of the people of hill areas and relates to agricultural productivity and sustainability. Countries with strong capacity in modern technologies would be interested for effective implementation of Plant variety Protection as envisioned in Trade Related Intellectual Property Rights (TRIPS) under the regime of World Trade Organization and, Private sectors investment is increasing in these countries because of increasing profit prospects in modern biotechnology sector where competition for exclusive rights for gene structures or gene sequences through patents is high. Countries rich in genetic resources, like India, would be more interested in implementation of the provisions of the CBD to honor the national sovereign rights on genetic resources, prior informed consent for the access of the material sharing of benefits and rewarding farming communities for their roles in conservation and management of genetic resources to meet their present needs and aspirations of future generations.

With the advent of substantial improvements in biotechnology and insufficient naturally occurring plants to meet the increasing demands of the medical markets, more wild medicinal plants with promising economic value have been identified and cultivated. Among these, wild yam (*Dioscorea* spp.) is a good example. The discovery of diosgenin, a steroidal sapogenin that occurs naturally in very high levels in some yam species, led to a revolutionary means of synthesizing birth control agents. Since the strict Birth Control Plan was carried out in China from the 1970s onwards, demands for contraceptive pills increased very rapidly, leading to the investigation, analysis, cultivation, and processing of yams. Over-exploitation has threatened yams in the wild and they are now being cultivated in western Sichuan especially for diosgenin production. From 1996 until about 2000, the number of households in Maoxian County involved in the cultivation of wild yams rose to around 1,000.

Due to the simple skills required, a minimal input of labour, a guaranteed output of products, the fact that farming field space did not have to be taken up, more and more farmers are involved in this industry on a voluntary basis. Various schemes has contributed to farmers' participation in development projects sponsored by government or development agencies aiming at poverty alleviation in this region. The cultivation of high-value wild or introduced plants by farmers has played an important role in their economy. Meanwhile, the policy of encouraging diversified economic activities, as adopted by the provincial government in 1980, has also had a positive impact on the development of sideline production. When the state monopoly for the purchasing and marketing of all specialized local products (except musk) was rescinded in 1985, the farmers perceived this as a crucial incentive to exploit wild plant resources. Subsequently, business organizations at all levels have been engaged in the purchasing and marketing of all medicinal plants. Indigenous agro-ecosystems have played an important role in the conservation of biodiversity, and some ethnobotanical practices of agroforestry management have been integrated into the reforestation projects.

Cryopreservation

Experiments were initiated on cryopreservation of *A. heterophyllum* and *P. hexandrum* seeds collected in the year. In *A. heterophyllum,* the initial moisture percentage was low (6%) and were therefore directly stored under liquid nitrogen. The seeds were retrieved after regular intervals for evaluation of viability, germination and cryoinjury. Seeds showed about 90-100% germination after 30 days storage. However, there was a higher ion leakage in the seeds stored for 30 days as compared to the seeds stored for 10 days only. The seeds of *Podophyllum* had much higher initial moisture content (50%) and were therefore initially desiccated to 10 and 5 moisture levels and then stored in liquid nitrogen. Further time interval studies and development of protocols for liquid nitrogen storage were undertaken.

NOVEL PRODUCTS FROM WESTERN HIMALAYAS

Rhizosphere exploration for PGPR (Plant growth promoting responses) was often associated with enhanced plant growth and crop productivity, particularly under conditions of poor availability of mineral nutrients and stressful milieu. Aimed at developing plant growth promoting formulations for economically important crops of Lahaul and Spiti, evaluation of carrier-based microbial inoculants was initiated in multi-location trials. The microbial formulation was based on a consortium of efficient and stress tolerant phosphate-solubilizing and nitrogen-fixing rhizobacteria, selected for high PGPR activity under controlled environment. The phylogenetic relationships were worked out for these phosphate-solubilizing PGPR. Stress-tolerant and efficient phosphate-solubilizing bacterial isolateswere also subjected to diversity analysis with PCR-RFLPof 16S rRNAgene, employing the four-base-cutting restriction enzymes *Alu I*, *Rsa I*, *Hae III* and *Taq I*. Five distinct restriction patterns, with 3 to 5 restricted fragments/ pattern, were obtained with the restriction enzymes

Why biotechnology and biodiversity conservation are closely linked

Various institutes play a significant role in the conservation of plant resources in this region. To maintain their precious germplasm, a large number of medicinal and other economically useful plant taxa are grown in the medicinal-plant section as well as in its high-altitude extension. Agro-techniques for several of these and other potential bioprospective taxa have been developed for their successful mass propagation. Emphasis is laid on growing *ex situ* collections of Rare, Endangered and Threatened (RET) taxa of the region **(Dar & Naqshi 2002).** By virtue of these projects, a large proportion of our precious plant germplasm, collected from far-off and difficult habitats, has been maintained *ex situ*. Various ongoing research projects pertain to the conservation of medicinal plants, being funded by the Ministry of Environment & Forests (MoEF), Govt. of India, Department of Biotechnology (DBT) Govt. of India, and the G. B. Pant Institute of Himalayan Environment and Development (GBPIHED), Almora, India.

Biotechnology and biodiversity are undoubtedly closely linked, especially if one uses a broad definition of biotechnology that includes pharmaceutical uses of natural compounds, and not just genetic engineering. Broadly biotechnology is perhaps best defined as '*any technique that uses living organisms (or parts of organisms) to make or modify products, to improve plants or animals, or to develop micro-organisms for specific uses*' **(US OTA 1991).** However, because the pharmaceutical, agricultural, environmental and genetics industries are those who are funding the bulk of bioprospecting efforts, they will receive most of the focus **(Ernst & Young 1995)**.

The biotechnology industry's boom is a relatively recent one. The rise of firms devoted exclusively to biotechnology research and development started in the 1970's and gained momentum in the 1980's and especially the 1990's **(Acharya 1999).** While in strictly economic terms multinational 5 companies remain far more important that small companies devoted exclusively to biotechnology (multinationals accounted for US$ 87 billion in annual sales in 1995, compared to US$ 9 billion for smaller firms), their rapid growth accurately reflects the growing importance of biotechnology, and such small companies are often at the forefront of bioprospecting efforts, and therefore particularly significant in light of links to biodiversity conservation.

As of now, the biotechnology industry is overwhelmingly located in the developed world. The lack of resources devoted to scientific research and a weak institutional regime in which public research institutions such as universities are poorly linked with private sector companies has made it difficult for biotechnology firms to establish themselves. This is particularly true when one looks at more modern biotechnology techniques – those of more interest to the pharmaceutical industry, and those most likely to be the focus of bioprospecting efforts – although a number of countries in east Asia, as well as Brazil, Mexico, Cuba, India, and China, are currently funding research in such areas. In other parts of the developing world, such as Africa, biotechnology research efforts are even further behind, and indeed most African countries have no institutions in charge of coordinating biotechnology research on a national level. It would be therefore expected for the biotechnology industry to reflect the views of developed countries in international forums dealing with trade and environment issues.

In order for biotechnology to exist as an industry, it needs a reservoir of biological and genetic material from which to draw its resources: the planet's biodiversity is therefore of fundamental importance to the industry. At the most basic level, many patents deposited by biotechnology firms are simply natural compounds found in certain plants and animals which may have beneficial medical, agricultural or other uses. In the US, the anti-coagulant properties of the venom of two Asian and South American pit vipers (*Agkistrodon rhodostoma* and *Bothrops athrox*) have been patented, while in Europe the therapeutic applications of extracts from the Indian plant *Cammiphora mukul* have also been patented **(Acharya 1999).** Both of these cases deals with compounds found in nature that can be used with little further elaboration from man, showing that often the biotechnology industry is dealing directly with the discovery and use of particular taxa.

Can the use of biotechnology promote biodiversity conservation?

This has led to the idea that biotechnology can help promote biodiversity conservation. The basic premise is that biodiversity contains hidden assets of potentially huge value to humanity, such as useful medical compounds found in plants or animals, new or better food crops. The search for new commercial applications for plant and animal species therefore gives biodiversity a significant enough innovation option value that biotechnology companies would be willing to pay for its preservation, and as such conserving a patch of biodiversity rich rainforest, for example, becomes more financially viable than converting it to farmland. The opportunity costs of biodiversity conservation would then be offset by the potential gains. Furthermore, as the private sector recognizes the economic value of biodiversity landowners and local communities in biodiversity rich areas will recognize the value and the potential benefits of their natural resources and will find it profitable to work towards their conservation.

Bioprospecting plays a key role in this argument. Bioprospecting refers to research undertaken in high biodiversity areas in order to discover potentially useful properties in local plants and animals, which can then be developed by the biotechnology industry. In many ways it is a form of basic scientific exploration. In fact, when one considers that only about 1.75 million of an estimated 14 million species of plants and animals have been described and named (World Conservation Monitoring Centre 2000; although some estimates run as high as 100 million species),bioprospecting can contribute to global biodiversity conservation in the most basic way, by contributing to the global inventory of known species. The compounds most sought after by the biotechnology industry are usually found in plants, of which 270 000 of an estimated 320 000 species have been described **(WCMC 2000).** This figure however is deceptive, as only about 25% of the world's estimated plant species are currently held in botanical gardens, and thus easily accessible to scientists **(Acharya 1999).** Furthermore, only a small percentage of these have been fully studied in order to identify their chemical properties, and bioprospectors are therefore taking the first steps in studying poorly-known taxa and contributing to global knowledge about biodiversity. The general way these efforts have been undertaken has been for a country to allow access to its genetic resources, and for prospectors to then identify and collect potentially useful taxa, which are then evaluated for potential use by the biotechnology industry. The countries from which these genetic resources come from are then compensated by the companies involved in the research, either through royalties paid on the use of commercially viable compounds, or though a "prospecting" fee paid in advance.

The argument that bioprospecting and biodiversity conservation could be positively linked first surfaced in the 1980's and gained strength in the 1990's. These arguments initially focused on the potential undiscovered economic value of biodiversity, especially with regards to the pharmaceutical industry. Early studies tried to estimate biodiversity's value to the pharmaceutical industry by estimating the probability of discovering a commercially valuable substance, and multiplying it by the value of the discovery **(Simpson et al 1996)**. While the results of these studies were extremely variable, most suggested that the untapped economic potential of biodiversity was quite significant, with estimates running as high as US$ 27.3 million per untested species in situ **(Principe 1989).** The link between bioprospecting and biodiversity conservation was further bolstered by some important discoveries. A much-publicized example is that of the rosy perwinkle *Catharanthus roseus,* a wildflower native to Madagascar used in traditional medicine there. The plant was found to contain alkaloids active against leukemia, and it is now used to treat cancer, Hodgkin's disease and is the best known-treatment for childhood leukemia (the synthetic compound used to treat childhood leukemia is only 20% as effective as the natural alkaloids found in the rosy perwinkle). This discovery was highly touted and served to put bioprospecting on the map as a possible strategy to promote biodiversity conservation.

The discovery of the anti-cancer properties of the bark from the Pacific yew tree *Taxus brevifolia* was also crucial in highlighting the value of biodiversity to the pharmaceutical industry. The discovery of taxol not only strengthened the argument that important discoveries were still to be made through bioprospecting, but more importantly from the pharmaceutical industry's point of view it proved that such discoveries could be immensely valuable from a financial standpoint, not only as a short-term return on the initial investment but also as a long-term source of income. It also provided a blueprint for other bioprospecting and biodiversity development agreements between the private sector and government institutions **(Day-Rubenstein and Frisvold 2001).** In particular, the attention of pharmaceutical companies was quickly drawn towards the developing world, where the potential for new discoveries was far greater due to their richer ecosystems, whose levels of biodiversity were both far higher and far less studied than they were in developed countries. This however created artificially high expectations in many developing countries about the potential economic benefits to be achieved thanks to bioprospecting, and meeting such expectations has become a major issue in assessing the success of these efforts.

Other studies have built upon and refined **Simpson *et al* (1996)'**s model, in some cases changing some of the basic assumptions, and the results have been somewhat more encouraging. **Rausser and Small (2000)** expand upon Simpson et al's (1996) work by identifying a key flaw in their argument. Simpson *et al* assumed that research on the potential value of species was random, all species being tested in the same way; as a result, the odds of finding a valuable compound for any given species are extremely low. **Rausser and Small (2000)** however assume that research on the potential pharmaceutical value of previously unstudied species concentrates on those that are likely to contain useful compounds, through models that identify the most promising research areas and leads. Indeed, bioprospecting efforts do not take place randomly across the world, but are concentrated in areas and ecosystems where potentially useful taxa are expected to occur, or on species that are closely related to those that have already proven to be commercially viable – for example, taxol is now being extracted from the Himalayan yew tree, a close relative of the Pacific yew from which the drug was first extracted. The odds of finding useful compounds are therefore significantly higher than those calculated by **Simpson *et al* (1996),** who assumed that bioprospectors operated without prior information to help them focus their efforts. It suggests that bioprospecting can be an efficient incentive mechanism for conserving biodiversity rich areas. Furthermore, Rausser and Small (2000) suggest that firms' willingness to pay for bioprospecting rights may be even higher in light of the competition for patenting new discoveries, as firms may be willing to pay a premium for exclusive access to promising areas.

FUTURE STRATEGIES

The main question is whether bioprospecting can generate enough socially sustainable profits to serve as a useful tool for biodiversity conservation. An optimistic answer is that it can, at least on a local level, if the conditions are right. Early estimates on the economic potential of bioprospecting were widely divergent. The most optimistic of these, which suggested that profits from bioprospecting could be high enough to serve as a significant force for biodiversity conservation, have proven to be overstated. However, a number of carefully structured biodiversity sharing agreements have indeed been profitable, both for the private sector and for the developing country institutions with which they have been signed and can serve as blueprints for future such efforts. Indeed, it should be noted that one of the most successful aspects of such agreements, perhaps even more important than the financial rewards, has been the investment in capacity building in developing countries, and the benefits in training for local biodiversity conservation technicians that have arisen **(Porzecanski *et al,* 1999).**

In order for bioprospecting to fully contribute to biodiversity conservation, local communities, the ultimate stewards of biodiversity, must be fully involved and receive enough benefits to offset conservation costs. The major challenge for successful bioprospecting efforts in the future will be to more fully integrate local communities in their efforts. This issue has been relatively overlooked so far, and apart from a few success stories where agreements were negotiated directly with local communities (as was the case with the Kani people in India), local communities have often been by-passed. Involvement of these communities is a critical step in protection of biodiversity.

The institutional framework in which these issues evolve is also crucial. At the moment, there is a conflict between the CBD, which reflects developing country interests and serves as a more effective framework for biodiversity conservation, and the TRIPs regime. Because of TRIPs' enforcement mechanisms, it is *de facto* the most relevant of the two in terms of influencing national and international policies. However, the CBD does have great resonance, and recent developments, such as the Doha conference, suggest that in the future TRIPs may move closer to CBD positions, thus providing a clearer and more favorable institutional framework. The outlook for the future of bioprospecting and biodiversity conservation is difficult to predict, but the fact that the issue remains at the forefront of current debate, and that there are ongoing developments on both the institutional and economic front, suggests that much work remains to be done. There is a growing realization of the need for a clearer institutional framework, and for better involvement of local communities, but until concrete steps are taken in this direction, success stories will remain scattered. Under ideal conditions, bioprospecting can be an effective way to preserve biodiversity locally, and it can play an effective, albeit limited role, in overall efforts to conserve global biodiversity.

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